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SEDIMENT BIOASSAY RESEARCH AND DEVELOPMENT

R. A. C. PROJECT NO. PDF 03

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EXECUTIVE SUMMARY

Under the 1987 revision of the 1978 Great Lakes Water Quality Agreement between Canada and the United States, the parties, in cooperation with state and provincial governments were assigned the task of cooperatively developing and implementing strategies for mapping, assessing and managing contaminated sediment. Adequate assessment of contaminated sediment requires information beyond bulk sediment chemistry. The biological significance of in-place pollutants can be measured on the basis of structural or functional modifications of benthic invertebrate communities, and by demonstrating the bioavailability of contaminants through a variety of toxicity tests.

Laboratory sediment bioassays are an important component of biological assessment. Bioassays range from acute lethality tests to chronic, sublethal tests. Chronic exposures provide information unachievable from acute toxicity studies. Growth, reproduction, and other physiological parameters have been used as endpoints in chronic tests. Since benthic organisms can be an important vector in the transfer of materials from sediment to other compartments of the ecosystem, the sediment bioassay should also provide information on the extent to which contaminants may be mobilized into the foodweb.

Biologically based sediment quality guidelines are under development by the Ontario Ministry of the Environment. These guidelines will, in part, provide the basis for making decisions on remedial actions. When bulk chemistry exceeds specified concentrations, the draft guidelines recommend that biological testing, including sediment bioassays, be conducted to identify whether contaminants are biologically available.

Sediment bioassays measure the effects of contaminated sediments on the biota. By far the most frequently described approach is solid phase testing with either benthic or water column organisms. For the purpose of evaluating the impacts of in-place pollutants on the biota, as opposed to the consequences arising from dredging operations, the focus of this study was on the solid phase bioassay.

The principle objective of this study was to contribute to the development of a methodology for assessing the chronic and acute toxicity of sediments to biota. This included an examination of the effects of bioassay assembly and sediment manipulation techniques to the response of the test organisms, and the sensitivity of growth as a chronic endpoint.

It is reasonable to expect that the exposure of an organism to contaminants will vary with the state to which the sediment-water system is in equilibrium. I therefore examined whether an organism's response varied with the length of settling time of the bioassay assembly proceeding the introduction of the organism. The duration of exposure required for the response of organisms in test sediments to differ significantly from the controls was also not known. As a result, the experiment was designed so that replicates could be harvested day 10 and day 21. Analysis of the growth response of Hexagenia suggested that biomass changes were influenced both by sediment type and by the duration of the period of equilibration. Growth in both test sediments was inversely proportional to the duration of the equilibration period.

In accordance with the biomass changes noted for mayflies, growth inhibition was least when the fathead minnows were added 5 days after chamber assembly. There appeared to be no notable difference between the 6 hr. (5 hr. settling plus 1 hr. aeration) and 1 day equilibration periods with respect to biomass changes. Metal accumulation was inversely proportional to bioassay settling time. The effects of fish density were variable. Growth inhibition was greater with 15 as compared to 10 fish in some, but not all cases, and density apparently exerted no influence on biomass changes in the controls. This last finding is of interest, since it may indicate that the stress of possible overcrowding was exacerbated by the contaminated sediments.

Exposing fathead minnows to test sediment for 21 days without food introduces additional stress which could exaggerate the adverse effects of contaminants. Feeding, however, could alter contaminant accumulation, and gut clearance may be important for estimating true tissue concentrations pf contaminants. A feeding experiment was conducted which revealed that feeding had little effect

on accumulation of trace metals and organic contaminants, however, significant decreases in concentrations of Mn, Fe, Al, Pb, and Ni resulted when fish were held for 24 h to purge their guts. Only for control organisms was growth improved by feeding.

Current methods for assembly of sediment bioassays often involve sieving and homogenizing the sediment. This effectively exposes the organisms to a uniform dose of contaminants that is in reality a mean dose of the heterogeneously distributed contaminants. In some cases, the extensive aeration of the sediment also results in a transformation of chemical species to forms that are of greater or lesser bioavailability. I examined the question of sediment homogenization by using diver-collected cores.

Intact sediment from one station resulted in higher mortality and poorer growth than homogenized sediments for mayfly nymphs, but did not significantly influence mortality or growth in fathead minnows. Intact sediment from a second station resulted in the reverse, better growth for mayfly nymphs and substantial mortality for fathead minnows. In a third station (sandy sediment), homogenization resulted in higher mortality than in the intact cores for Hexagenia. This was most likely caused by the elimination of the surface layer of fine-grained material (present in intact cores) and therefore, the elimination of suitable substrate for burial and feeding. Homogenization did not effect growth of fathead minnows, and may have ameliorated toxicity as measured by mortality.

Sediment manipulation, bioassay assembly, organism density, and bioassay duration were important determinants of the final endpoints measured. Further efforts devoted at refining substrate and feeding requirements of test organisms would assist in calibration of the bioassays.

The results of this research support the use of a 21 day sediment bioassay with organisms introduced no more than 24 h after bioassay assembly. Several test organisms should be included in a comprehensive assessment. This work focused upon the mayfly nymph Hexagenia limbata and the fathead minnow Pimephales

promelas. Growth inhibition was demonstrated to be a sensitive indicator of sediment toxicity.

Further research into the development of full or partial life cycle tests that include reproduction as an endpoint is warranted, and establishment of cultures for all test species, along with the use of reference toxicants, would be of great value for ensuring repeatability of bioassay results.

Integrated strategies for sediment management must include a consideration of biological effects observed both in the laboratory and *in situ*. An array of biological test methods can provide an integrated approach to the determination of the toxicological qualities of sediment contaminated with a variety and sometimes unknown chemicals. Sediment bioassays are a valuable vehicle for the assessment of sediment and provide information that reflects the biologically relevant forms of mixtures of contaminants.

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1.0 INTRODUCTION

The principle objective of the research conducted under the Research Advisory Committee, Ministry of the Environment Post-Doctoral Grant PDF03 was to develop a methodology for assessing the chronic and acute toxicity of sediment to biota and to determine the bioavailability of sediment bound contaminants by measuring tissue retention of polar and nonpolar substances.

To achieve this goal, the following studies have been conducted:

- Examination of the effects of bioassay assembly and sediment manipulation techniques upon the response of the test organisms.

- Assessment of the relative sensitivities of a series of endpoints, including:

  - growth inhibition
  - bioaccumulation
  - mortality

- Comparison of the responses of organisms occupying different ecological niches including:

  - benthic infauna e.g. mayfly
  - water column organisms e.g. fathead minnow

- Establishment of an interim recommended protocol for multiple organism/endpoint bioassays to be conducted in concert with field collections of benthic macroinvertebrates for the assessment of community structure and physiochemical analyses of in situ contaminants.

In addition, the following studies are recommended:

- Estimation of the comparative sensitivity of the amphipod Hyallela

azteca and Chironomus as alternate bioassay organisms, and the establishment of invertebrate cultures for these organisms and for Hexagenia limbata.

- Development of full or partial life cycle tests with reproductive success as an additional endpoint

- Introduction of the routine use of reference toxicants as a means of ensuring comparable sensitivity of test organisms for each bioassay conducted

- Calibration of growth on the basis of substrate conditions

- Further investigations into sediment manipulation with consideration of the sensitivity of endpoints to static, static-renewal, and flow through systems

2.0 OVERVIEW OF SEDIMENT BIOASSAY METHODS

Currently, the literature contains several approaches to sediment bioassessment with references to a range of benthic and water column organisms and various lethal and nonlethal endpoints. It is useful to summarize ongoing research in the field, to better understand the context within which this report applies.

Sediment bioassays measure the effects of contaminated sediment on biota. Examining this broad statement more closely reveals the potential for a myriad of test designs. The substrates which have been explored include sediment elutriates, pore waters, and whole, sieved or suspended sediments. Chamber construction ranges from petri dishes and test tubes to 40L aquaria with static, static/renewal, flowthrough, and recycling water regimes. Test organisms are benthic infauna or epifauna, macrophytes, fish or plankton. The bioassay responses or endpoints vary from acute lethality to nonlethal impacts during acute or chronic exposures. These range from the molecular and cellular levels such as biochemical deviations and induction of carcinomas, to the organismal

level such as growth and reproductive inhibition. To avoid confusion, it is worthwhile noting that the terms acute and chronic refer to exposure duration while the enpoints may be lethal or nonlethal. The most sensitive assays are those that utilize chronic exposure intervals and monitor for nonlethal toxicity reponses of critical life stages of sensitive organisms. The bioassay assembly can also be applied to monitor bioaccumulation of pollutants by the test organism in order to estimate contaminant bioavailability and potential for foodweb mobilization of potential toxicans.

2.1 Matrices used for biological assessment of sediments

Sediment elutriates have been prepared as liquid phase matrices, principally to assess the impacts of dredging activities on water column organisms (Gannon and Beaton 1969, Lee et al. 1975, Shuba et al., Munawar et al. 1983). For example, the USEPA/US Army Corps of Engineers (1977) describe a 48h toxicity test that exposes Daphnia to the elutriate.

Pore waters have been considered as an alternate liquid phase to examine the effects of contaminated sediments on the burrowing infauna and to identify the route of exposure of different organisms to different pollutants (Bahnick et al. 1980, Rodgers, J.H., Jr., N. Texas State Univ., pers. comm.). The interstitial waters may be acquired by squeezing sediment, centrifugation followed by filtration, or through the use of dialysis membranes.

By far the most frequently described approach is solid phase testing with either benthic or water column organisms (e.g., Swartz et al. 1985a, Malueg et al. 1984, Cairns et al. 1984, Ingersoll and Nelson, 1987). For the purpose of evaluating the impacts of in-place pollutants on the biota, as opposed to the consequences arising from dredging operations, this research program centred on the solid phase bioassay. Studies based on pore waters are scant, although of potential significance particularly with respect to understanding the mechanisms involved in the bioaccumulation of contaminants. Nevertheless, the remainder of this review will be dedicated to solid phase testing with a variety of organisms primarily due to its conceptual simplicity and relatively greater compatibility with field conditions.

2.2 Endpoints

2.2.1 Acute Toxicity Bioassay

Sediment bioassay reviews by Nebeker (1984), Buikeman (1982), Munawar et al. (1984), Craig (1984) and Lamberson and Swartz (1985) all demonstrate the preponderance in the literature of relatively short-term exposures with mortality as an endpoint. Acute tests typically measure the lethality of the test sediment relative to a reference substrate. Acute tests are frequently conducted by placing a specified volume or depth of sediment in a beaker, jar or aquarium. This is followed by the addition of a volume of water, often at a ratio of 4:1 (v:v) of water to sediment (Nebeker et al. 1984). The assembly is either static, flowthrough or recycling, and aeration is normally indicated. Several organisms are added to replicate units and mortality is tabulated by the end of the exposure. Exposure times vary among organisms and for the same organisms being employed by different authors. Table 1 lists a number of acute bioassays that have been described for freshwater and marine fauna.

2.2.2 Sublethal Chronic Sediment Bioassays

Chronic tests provide critical information which cannot be secured from acute toxicity studies, especially where the contaminants are materials with delayed action and of bioaccumulative potential. When an organism's life stage influences its degree of sensitivity to pollutants, chronic studies are capable of detecting significant adverse biological impacts of polluted sediment that would not be observed in an acute test. In some instances, behavioral modification may result from exposure to contaminated substrates (Swartz 1985a) and this can have consequences for an organism's ability to compete for resources, reproduce, and/or avoid predation in nature.

Growth, reproduction, and other physiological parameters have been used as endpoints in chronic bioassays (Nebeker et al. 1984) as have behavioral activity such as burrowing (Swartz 1985a) and preference/avoidance (Gagnon

and Beeton, 1969, 1971). Table 2 summarizes some of the endpoints which have been considered for a number of different taxa.

In addition to the endpoints listed in Table 2, biochemical, enzymatic, histopathological and morphological changes have also been measured. These have been reviewed by Beak (1987) and will not be considered in detail here. While these latter options can provide sensitive early indications of organism stress, the approaches currently require a degree of technical skill, expertise, laboratory specialization, and financial resources that are sufficiently great as to preclude their integration into a routine protocol.

2.2.3 Bioaccumulation

Measurements of tissue concentrations of polar and nonpolar substances can be used to demonstrate that contaminants in sediment are biologically available and have the potential to enter the food web. Nebeker et al. (1984) include tissue analysis of chironomids, mayflies and amphipods in their bioassay approach. Since benthic invertebrates can be an important vector in the transfer of materials from sediment to other compartments of the ecosystem (Krantzberg 1987) the sediment bioassay should provide information on the extent to which contaminants may become mobile.

Currently, the toxicological significance of tissue residues in invertebrates and many vertebrates is virtually unknown. Unfortunately, assessing this linkage falls beyond the scope of this research, at present. It should be stated, however, that for an organism to metabolize or detoxify contaminants, there is undoubtably a physiological cost in the production of enzymes and other proteins. Energy diverted from normal metabolic pathways for these purposes could be quantified and the ramifications at the level of the organism should be established.

2.3 Sediment Bioassay Design

Having outlined the variety of test organisms and endpoints of potential use, it is instructive to explicitly consider the many decisions that modify the end

result of the bioassay. From a biological perspective, factors such as organism size, age, sex, reproductive status, and history of exposure to pollutants can alter the response of an organism to a given sediment (Luoma 1983, Krantzberg and Stokes 1989). Clearly, interspecific variability should also be expected and is often observed. This has led to recommendations that several taxa be used for each bioassay (e.g. Nebeker et al. 1984). From a population standpoint, density dependent effects may also be postulated and should be confirmed or refuted. From a physical and chemical perspective, different methods of sediment storage, manipulation, chamber construction and assembly, could effect the outcome of the bioassay. Sediment handling necessarily disrupts sediment physicochemistry which has direct implications for contaminant activitiy.

These biological, physical and chemical processes were recognized in the development of a research program directed at on the importance of bioassay design. Recommendations for the application of the results are presented in the form of a detailed protocol (Section 5.0).

3.0 EXPERIMENTAL DESIGN, RESULTS, AND DISCUSSION

The first set of experiments examined the effects of equilibration time of the bioassay assembly and bioassay duratation on mortality, growth and bioaccumulation by the mayfly nymph, Hexagenia limbata and the oligochaete Tubifex tubifex. The second experiment considered the effects of organism density, chamber equilibration time and bioassay duration on mortality, growth, and bioaccumulation of contaminants by juvelines of the fathead minnow, Pimephales promelas. The third series of test bioassays examined the consequences of feeding with respect to mortality, growth and bioaccumulation of contaminants by P. promelas. The fourth bioassay assessment compared the toxicity of homogenized sediments with that of sediment collected by diver and maintained as intact cores. Test organisms for the latter experiment were mayfly nymphs and fathead minnows. For all investigations, pH and dissolved oxygen were routinely measured.

3.1 Experiment 1 - March 1 to March 25, 1988

Purpose: To determine the effects of settling time, following the addition of sediments and water to the bioassay container, on sediment toxicity to oligochaetes and mayflies. To evaluate the importance of bioassay duration on identification of toxic sediment. To determine trace metal and trace organic bioaccumulation by oligochaetes as a function of bioassay design.

It is reasonable to expect that the exposure of an organism to contaminants will vary with the state to which the sediment-water system is in equilibrium. I therefore examined whether an organism's response varied with the length of time for which the bioassay assembly was left to settle prior to the introduction of the test species. The duration of exposure required for the response of organisms in test sediments to differ significantly from that of the controls was also not known. The experiment was therefore designed so that half of the replicates could be harvested at day 10 and half could be harvested at day 21.

The two test sediments were from a silty site in the vicinity of the Toronto Main STP outfall and a sandy site at Rice Lake. The control or reference sediment was a silty substrate from Honey Harbour. Two litre widemouth glass jars were filled to a depth of 3 cm with sediment (surface area = 100 cm^2) and dechlorinated tap water was gently added. Organisms were introduced at 3 time intervals; 5 hours settling plus 1 hour of aeration, 1 day settling plus 1 hour aeration and 5 days settling plus 1 hour aeration. At each time interval, either 8 mayflies weighing approximately 25 mg/individual (wet weight) or approximately 1.5 gm (wet weight) of oligochaetes (c.a. 150 individuals) were introduced into the chambers. Each treatment had 4 replicates. Preliminary tests indicated no density dependent effects for mayflies at this density.

Sediment bulk chemistry and physical properties were measured at the onset of the experiment (Tables 3 and 4). Oligochaetes were held in dechlorinated water overnight to evacuate their gut contents and were frozen and submitted for metal and trace organic analysis. Mayflies were weighed and counted, but were of

insufficient biomass for analysis.

Analysis of the growth response of Hexagenia indicated that biomass changes were influenced both by sediment type and by the duration of the period of equilibration (Table 5). Growth in both test sediments was greatest when the mayflies were added when 5 days had elapsed following chamber assembly. Growth was poorest when organisms were added when 6 hours had elapsed following assembly (1 hour after aeration).

Mayfly biomass increased most in nymphs exposed to control sediments, followed by organisms exposed to Rice Lake sediment, and increased least in mayflies subjected to sediment from the vicinity of the Toronto Main STP. Growth inhibition relative to controls was more pronounced by day 21 ($p < 0.05$), as compared to day 10 (Fig 1).

Due to difficulties in assuring retrieval of all oligochaetes, bioamass changes were not considered as an endpoint in the bioassay. Bioaccumulation results were interpreted by analysis of variance. Trace organic concentrations in oligochaetes (Table 6) did not vary significantly with experimental settling time and bioassay duration. Manganese and Al concentrations in oligochaetes (Table 7) were significantly different from time zero, with Al increasing with exposure time and Mn decreasing with exposure time. One hypothesis is that with sufficient aeration of the bioassay chamber, Mn became less bioavailable with time due to the formation of insoluble oxyhydroxides. The increase in Al concentrations in oligochaete tissues with exposure time may reflect the effect of sediment ingestion which was not mirrored by other trace metals either due to their relatively low concentrations in sediment, poor bioavailability, or active metabolic regulation by oligochaetes.

3.2 Experiment 2 - March 31 to April 25, 1988

Purpose: To determine the effects of settling time and bioassay exposure interval on sediment toxicity to fathead minnows and to establish whether toxicity is dependent on organism density.

The test design and bioassay assembly parallelled Experiment 1. The two test sediments were from a sandy site in the vicinity of the Toronto Main STP outfall and a silty site in St. Mary's River. Three to four month old juvenile fathead minnows weighing approximately 0.5 gm per individual were added to each bioassay chamber at a rate of 10 or 15 individuals per replicate. Four replicates of each treatment were harvested after 10 or 21 days exposure. Fish were reweighed and half were immediately frozen for metal and trace organic analyses. The remainder were held for one day in dechlorinated water to clear their guts and to illuminate the significance of short term depuration.

In accordance with the biomass changes noted for mayflies, growth inhibition was least if the fathead minnows were added when 5 days had elapsed following chamber assembly (Table 8). There was no notable difference between the 6 hr. (5 hr. settling plus 1 hr. aeration) and 1 day equilibration periods with respect to biomass changes, and the effects of fish density were variable. Growth inhibition was greater with 15 as compared to 10 fish in some, but not all cases, and density apparently exerted no influence on biomass changes in the controls. This last finding is of interest, since it may indicate that the stress of the exposure to contaminated sediments could be exacerbated by possible overcrowding .

By day 21, all fish had decreased in weight (Fig 2). Minnows from the test sediment lost more weight than did those from the control sediment and analysis of variance revealed that this outcome was significant by day 21 ($p < .05$).

Trace metal concentrations in fathead minnows were responsive to several bioassay treatments (Table 9). Less Pb was accumulated in the presence of 15 individuals than in the presence of 10 individuals, while the reverse was true for Al and Cd. The explanation for this remains unclear may warrant further examination. More gamma-chlordane was accumulated by fish at the higher density as compared with the lower density (Table 10). This phenomenon remained true when tissue concentrations were corrected for lipid content.

With the exception of Cd, metal accumulation was significantly greater ($p < 0.01$) when organisms were added to the bioassay chamber after 5 hrs of settling

plus one hour of aeration, as compared with longer settling intervals. In addition, As continued to increase with exposure duration while Cr decreased significantly with bioassay duration. No other significant differences in tissue residues were observed as a consequence of bioassay duration. Concentrations of trace organics in fathead minnows did not vary with settling time or exposure duration (Table 10).

The importance of permitting an interval for gut clearance in the final measurement of contaminant residues in fathead minnows is discussed under section 3.3.

3.3 Experiment 3 - April 26 to May 18, 1988

Purpose: To determine the effects of feeding on growth, bioaccumulation and mortality of fathead minnows in sediment bioassays.

Based on the results of Experiment 2, it was apparent that even control organisms were experiencing stress due to starvarion. In addition, there was evidence that the expression of toxicity was density dependent. Therefore, a feeding experiment was initiated employing 10 fish in each chamber, to be introduced to the chambers when 6 hours had elapsed after assembly. Contaminated sediments were from a silty site at Canagagigue Creek, a coarse sandy site from the Algoma slip (St. Mary's River), a silty site from Rice Lake and sandy site from St. Mary's River. Silty Honey Harbour sediment was used as a reference substrate. Bioassay design was as above, with a subset of the test organisms retained for 24 hours to depurate gut contents.

For each sediment, 4 replicates were fed ad libitum every second day and 4 replicates were not fed for the duration of the 3 week bioassay. Average biomass was c.a. 0.3 - 0.4 gms per individual (wet weight) at the onset of the experiment.

Both the Canagagigue Creek and Algoma slip sediments were lethal with mortality occurring from day 1 to day 14. No relationship between time until mortality and feeding was evident.

Since fathead minnows ingest sediment and consume detritus, biomass changes may be linked to substrate properties that are independent of contaminant loads. For chronic studies, then, standardizing food availability may be necessary. Introducing food, however, may complicate the interpretation of results, particularly with respect to bioaccumulation. The only organisms to show an increase in biomass were the minnows receiving food in the Honey Harbour treatment, while biomass was lost in the Honey Harbour, unfed minnows (Table 11). Interestingly, for the other contaminated sediments, feeding did not affect the extent of biomass lost, perhaps indicating that the presence of the pollutants significantly influenced fish metabolism. This finding is in accordance with the hypothesis that the additional stress imposed upon an organism by contaminants can amplify the importance of naturally encountered stresses such as food or habitat limitation.

Highly significant ($p < 0.001$) concentrations of Mn, Fe, Al and Pb, and Ni ($p < 0.02$) were lost when fish were allowed to purge their gut contents. The only effect of feeding was an increase in Ni concentrations in fathead minnows (Table 12). Trace organic concentrations did not differ among treatments (Table 13). The loss of Mn, Fe and Al may well reflect the importance of these elements in sediment composition and their correspondingly high concentrations relative to tissue residues in fish. The loss of Al agrees with the findings for depuration effects on oligochaete tissue residues. While metal physicochemistry was not measured, Pb and Ni are known to associate with Fe and Mn oxyhydroxides. Lead and Ni may have followed pattern of Fe and Mn for this reason.

3.4 Experiment 4 - June 30-July 22, 1988

Purpose: To compare the toxicity of intact sediment cores and homogenized sediment to mayfly nymphs and fathead minnows.

The current MOE method for assembly of the sediment bioassay involves sieving and homogenizing the sediment. This effectively exposes organisms to a uniform dose of contaminants that is in reality a mean dose of the heterogenously

distributed contaminants. A positive ramification of homogenization is that it most likely results in less variability among replicates than would be observed for intact sediment. In contrast, there are probably many circumstances where the extensive aeration of the sediment also results in a transformation of chemical species to forms that are of greater or lesser bioavailability. One approach to examining the question of how toxicity is influenced by sediment homogenization involves a comparison of endpoints achieved when organisms are exposed to diver-collected cores and to homogenized sediment.

The cores used were acrylic tubes of surface area comparable to the 2L glass jars. Organisms were introduced into the cores and into homogenized sediments from the same site as those where cores were collected.

Eight Hexagenia nymphs (c.a. 40 mg/individual net weight) or 10 juvenile fathead minnows (c.a. 400 mg/individual net weight) were the test organisms. Four replicate diver-collected cores and triplicate jars of homogenized sediment were used for each organism for each of three test substrates. Mortality, biomass changes,
and bioaccumulation over three weeks were the endpoints examined. pH and dissolved oxygen were monitored in all chambers.

One sandy and two fine-grained sites in the vicinity of the Toronto Main STP outfall were sampled. Honey Harbour sediments were used for controls. In Site A (fine), intact sediment resulted in higher mortality and poorer growth than homogenized sediment for mayfly nymphs, but did not significantly influence mortality or growth in fathead minnows (Table 14). Intact sediment from Site B (fine) resulted in better growth for mayfly nymphs than homogenized sediment. Mortality was <10% in both treatments. Homogenization resulted in substantial mortality for fathead minnows (87% vs 20% in intact cores). In Site C (sandy) homogenization resulted in higher mortality than in the intact cores for Hexagenia. This was most likely caused by the elimination of the surface layer of fine-grained material (present in intact cores) and therefore, the elimination of suitable substrate for burial and feeding. Homogenization did not effect growth of fathead minnows, and may have ameliorated toxicity as measured by mortality. A point of interest is the variability in response between the two

test species, which suggests differential modes of action of contaminants upon organisms with vastly different metabolic pathways and ecological niche requirements.

The results the chemical analyses of tissue residues for trace metals are illustrated in figures 3 through 7. While there was a tendency for some metals to bioaccumulate to a greater extent in beakers as compared to core exposures, the results were not statistically significant. Considering the high cost of diver collected cores, this result is encouraging, in the sense that the beaker assay may be fairly representative, if not more conservative than intact core bioassays. The finding that intact cores were more toxic to mayflies at station A but not at station B should be perceived as justification to pursue this line of investigation and to broaden the range of sediment tested.

4.0 RECOMMENDATIONS FOR RESEARCH PRIORITIES

4.1 Chronic Bioassays

Recommendation

I strongly urge that the development of chronic, nonlethal bioassays be the central focus of future research. This has begun with a consideration of a 21 day growth-inhibition test with mayflies and fathead minnows. Clearly, mortality is also documented and many other potential endpoints could be adopted.

Since sediment organic content will effect growth, independent of the level of contamination, additional studies on feeding must be performed for fathead minnows in particular. Food availability has been shown to modify the bioaccumulation of pollutants and studies designed to further assess various feeding regimes for chronic bioassays are strongly recommended.

The chironomid full or partial life cycle test is worth pursuing. Survival, changes in biomass, emergence, and reproductive success can all be measured in 10 to 28 days. Several organisms can be introduced into a single chamber (with replication) or individual organisms can be held in test-tube assembly. These two approaches could be compared.

Hyallela azteca is also amenable to a full or partial life cycle test, but ensuring that individual sensitivity remains constant during culturing may be somewhat more difficult for the amphipod than for the chironomid.

A sensitive and more rapid chronic bioassay measures growth in larval or egg-sac stage fathead minnows. This test has been considered for effluent testing and could be applied to sediment bioassessment.

Another interesting class of endpoints to consider is behavioral in nature. The two most often cited are preference-avoidance and inability (or refusal) to burrow. I have observed oligochaetes to remain on the surface of noxious

sediment. Mayflies also elicit this response, although less frequently. Others have demonstrated reburial failure in amphipods transferred to clean substrates following exposure to contaminated sediments. These endpoints, however, my be more difficult to interpret in terms of their ecological significance than the partial life cycle tests and should be investigated once the former tests have been established.

4.2 Reference Toxicants

Recommendation

At least 1 polar (e.g. Cd) and 1 nonpolar (e.g. PCP) compound should be tested and effect concentrations established. These pretests, or positive controls, can be conducted as $EC_{,,}$s or $LC_{,,}$s in aqueous phase bioassays or developed as a spiked sediment bioassay.

Reference toxicants have been of value in examining seasonal changes in an organism's sensitivity, and changes related to age, reproductive status, and history of exposure to contaminants. In order to ensure that the test organism's response to contaminants is uniform and does not vary among bioassays (or among laboratories), reference toxicants should be incorporated as a pretest in all bioassays. Loss of vigour in cultured organisms has been demonstrated and could confound interpretation of sediment bioassay results. When an organism response does vary, one might justify the application of a correction factor.

4.3 Sediment Manipulation

Recommendation

Further comparisons between intact sediments and homogenized sediments should be initiated to assess the effect of sediment manipulation on acute and chronic endpoints. The effects of sediment storage on toxicity should also be investigated.

Many existing protocols, including the current MOE method for assembly of the sediment bioassay involve sieving and homogenizing the sediment. For many sediments extensive aeration will result in a transformation of chemical species to forms that are of greater or lesser bioavailability. One approach to examining the question of sediment homogenization involves comparisons of toxicity with diver-collected cores. The cores should be of comparable surface area as the glass jars being used for routine testing. Organisms can be introduced into the cores and into sediment which will be sieved and homogenized and collected from the same site as those where cores were retrieved. Since the objective of the bioassay is to assess the extent of contamination of the sediment directly, without the complicating factor of potentially contaminated site water, dechlorinated laboratory water should replace the water in the cores and should be used for the jar test as well. I conducted one such experiment (Section 3.4) and the results should be verified for other sediment types and additional bioassay organisms.

As an alternative to toxicity testing using diver collected cores, the contents of the ponar grab can be "cored" on board with minimal mixing of the test sediment. These pseudo-cores can be returned to the laboratory and subjected to the same bioassessment as the diver-collected cores and the homogenized sediment. Again, it would be useful to conduct the above experiments using a variety of organisms and a broader range of contaminants.

Due to logistical constraints sediment has in the past been stored at 4°C for several months prior to conducting the bioassay. To establish a maximum acceptable storage interval bioassays could be repeated using the same sediment after short and long-term storage (e.g. 2 weeks, 1 month, 2 months, 6 months storage).

4.4 Invertebrate Cultures

Recommendation

To facilitate the development of a multi-species approach to sediment bioassessment, invertebrate cultures should be initiated. The construction of

facilities at MOE for culturing Hyalella azteca, Hexagenia, Chironomus, and oligochaetes should be expanded and actively maintained. Protocols for culturing these invertebrates have been published by, for example, S.G. Lawrence (ed) 1981, as a Canadian Special Publication of Fisheries and Aquatic Sciences #54. It would be worthwhile for a full time technician and/or scientist to adopt responsibility for the maintenance of the cultures.

Since sensitivity to contaminants varies among species and one species is not necessarily the most sensitive to all classes of pollutants, MOE should adopt an approach that incorporates the responses of several taxa. The test organisms should represent different ecological functional groups such as filter-feeders, burrowing infauna, and benthic foraging fish, for example. Chironomus riparius can be easily cultured and used for a partial life cycle test. Collection of sufficient quantities of Hexagenia that are of a prescribed age and size is problematic and labour intensive. Establishing mayfly cultures, then, would be of great value. Hyalella has been successfully maintained in stock cultures and reproduction can be induced easily by controlling the photoperiod. Partial life cycle tests with the Hyalella would be facilitated by establishing laboratory cultures although maintaining consistency in culture vigour must be verified. Oligochaetes can be used to measure reproductive success and contaminant bioavailability as reflected by bioaccumulation. Tubificids are easily maintained in the laboratory.

4.5 Organism Age and Size

Recommendation

I have compared the response of several size classes of mayflies and fathead minnows exposed to contaminated sediments. These experiments should be conducted for all test species.

Sensitivity to contaminants and contaminant bioaccumulation has been shown to vary with age and body size for several taxa. For purposes of tissue analysis, larger organisms provide greater biomass. However, sensitive life stages are

generally early life forms. Increased replication with smaller organisms may satisfy both needs.

4.6 Substrate Properties and Colonization Potential

Recommendation

The range of substrates that the test species can potentially colonize, in the absence of contamination, must be determined. Growth rates in sediment of different organic content should be established.

Organisms such as chironomids and burrowing mayflies exhibit substrate preferences. The absence of Hexagenia from a coarse-sandy sediment, for example, may be due to its inability to thrive in such a substrate, regardless of how pristine it may be. Extremely soft oozy mud may be too unstable a substrate for chironomids. The organic content of a given sediment can be critical for growth and survival. In order to formulate decision criteria for the selection of test organisms based on substrate properties (independent of contamination), it is important to establish the range of substrates that the test species can potentially colonize.

For growth to be used as an endpoint in sediment bioassays, biomass changes should be calibrated against the same range of sediment types for uncontaminated substrates. One approach is to collect clean, fine sediments and perform a serial dilution with fine and coarse sand. These experiments should apply to all test species.

4.7 Sediment to Water Ratio

Recommendation

The effect of increasing or decreasing the currently adopted 1:4 ratio (volume sediment:volume water) should be measured to ascertain that this ratio is adequate.

The most frequently cited sediment to water ratio in a static test is 1:4 (v:v). Experimental manipulation of this ratio may reveal a graded response to the test organism. That is, toxic effects may increase when there is proportionally more sediment (or less water) in the system but may be independent of the ratio at relatively high volumes of water.

4.8 Flow-through, Static-Renewal and Static Water Regimes

Recommendation

A comparison of these three approaches, particularly in the case of chronic tests, would assist in verifying that the observed endpoints best reflect the biological significance of sediment contamination.

Static beaker tests are generally considered to represent a "worst case" or "conservative" scenario. If contaminants increase in the water column during the exposure interval, it is intuitively logical that some organisms will demonstrate toxicity responses that would not be observed in a flow-through system. It is possible, however, that under certain circumstances, flow through conditions may in fact underestimate the potential impacts of the test sediment on some organisms as would be observed in nature.

The build-up of metabolites during a chronic bioassay may complicate the interpretation of the results. A consideration of the static-renewal approach would therefore be of great utility.

4.9 Field Comparison

Recommendation

Following laboratory investigations on the ramifications of various bioassay design options, a thorough program of field testing should be instituted.

Field experiments should be designed to substantiate that laboratory tests are a meaningful representation of field conditions. In situ chambers containing the same species used in the laboratory can be positioned in the sediment. The endpoints measured would be those evaluated in the laboratory sediment bioassay. Careful consideration of chamber design, its introduction into the sediment, water flow and/or exclusion, controls for chamber effects, and other potential sources of artifact is integral to the success of the field validation program.

4.10 Bioaccumulation

Recommendation

It would be extremely beneficial to devote research efforts towards illuminating the relationship between the tissue retention of contaminants and their physiological significance to the exposed organism.

The relationship between the rate and extent of bioaccumulation of contaminants and their physiological effects are poorly understood. As a consequence, the ecological significance of tissue retention of pollutants cannot be established for many contaminants. Such information would be of great value in the establishment and implementation of sediment and biota guidelines.

5.0 RECOMMENDED PROTOCOL FOR LABORATORY SEDIMENT BIOASSESSMENT

The following recommendations for establishing a MOE protocol for sediment bioassays should be considered as a framework which will be further modified based upon ongoing research efforts in the development of the assays. It is anticipated that these recommendations will be complemented by recent findings of D. Bedard and A. Hayton, and that an MOE sediment bioassay protocol document will be prepared by these individuals and myself, based on available information. Further, the sediment bioassays should be recognized as an important component of a sediment management strategy that includes extensive biological assessment as well as chemical measurements.

Sample Collection

Sediment is collected by Ponar grab from test and control sites and the surficial 3 cm are placed in polyethylene-lined plastic buckets. These are returned to the laboratory and may be stored at 4°C for no more than 2 weeks.

Preparation of the Bioassay Chamber

In the laboratory, sediment is air-sieved through a 2 mm mesh to remove large particles, stones and other debris, and is then thoroughly homogenized. For the experimental bioassays, 2 L glass widemouth jars, acid washed and hexane rinsed, are filled to a depth of 3 cm with sediment (surface area = 100 cm^2). Dechlorinated water is gently added at a ratio of 4:1 water to sediment (v:v). Care must be taken to avoid having sediments adhere to the glass above the 3 cm level. Resuspended sediment is allowed to settle for 5 hours (more conservative) or 24 hours (logistically more practical), after which the overlying water is aerated for 1 hour by inserting airlines through the lids of the glass jars and securing the lids in place. Water loss due to evaporation is replaced as necessary in order to maintain a water to sediment ratio of 4:1. pH and dissolved oxygen in the overlying water are monitored routinely for the duration of the experiment.

Test Organisms

Presently, organisms for the experimental bioassays are three to four month old juvenile fathead minnows (Pimephales promelas) (acquired from OMOE Rexdale laboratory cultures) weighing approximately 0.5 gm wet weight and first year mayfly nymphs (Hexagenia limbata) weighing about 30 mg wet weight, collected at a clean reference site (Honey Harbour, Georgian Bay, Ontario) or cultured in the laboratory. Nymphs collected from the field can be maintained in the laboratory in glass aquaria containing reference site sediments with gentle aeration of the overlying water. The aquaria may be kept at <10°C, and gradually brought to 20°C as mayflies are required. Alternatively, mayflies can be cultured in the laboratory and harvested upon demand. Depending upon culture availability, second instar Chironomus tentans may also be used.

Several hours prior to experimental exposure, mayflies are removed from their aquaria by sieving small volumes of sediment through a 500 µm mesh. Nymphs are randomly allocated to beakers containing dechlorinated water until each beaker has 10 individuals of similar size (c.a. 25 mg/ individual, wet weight). The nymphs are weighed after blotting them on several layers of "Kim Wipes" or acid rinsed filter papers to remove adhering water. Alternately, when a large number of assays are run concurrently, 5 to 7 aliquots of 10 individuals each can be weighed, and the mean biomass used as an estimate of initial biomass.

Similarly, juvenile fathead minnows are randomly allocated to beakers containing dechlorinated water until each beaker has 10 individuals of similar size (c.a. 0.5 gms/individual, wet weight). Wet weight of each group of 10 individuals is measured, or 5 to 7 representative samples of ten individuals each can be wieghed, as above.

Chironomid length, weight, and head capsule widths can be measured for a representative subsample of individuals at the onset of the experiment.

Conducting the Bioassay

A minimum of 3 replicate jars of each bioassay organism. Organisms are added when 5 to 24 hours of settling followed by 1 hour of aeration have elapsed. Aeration persists for the duration of the 21 day exposure interval. All control and test jars are maintained at 20°C (a water bath may be required) at ambient light.

During the 21 day bioassay period, mortality is noted and dead organisms are removed. The presence of mayfly exuvia should also be recorded. As stated above, pH and dissolved oxygen are monitored and water lost due to evaporation is replaced. At day 21, organisms are removed from the bioassay jars by passing the entire contents of each jar through a 500 µm sieve and retrieving the biota. Recoveries are noted and the remaining organisms are reweighed and measured using the procedure described above.

Chemical Analyses

Mayflies and fathead minnows are placed in hexane-rinsed aluminum-foil for analysis of organic residues, or in plastic (e.g. "whirlpak" bags) for metal analysis. Depuration is currently not recommended for trace organics, however, the importance of gut clearance prior to sample analyses may be of relevance for some trace metals. If feasible, a subsample of test organisms are held in dechlorinated tap water for 24 hours to permit the depuration of gut contents. Samples are frozen until chemical treatment can be conducted. Biota must be handled gently, using teflon-coated or nylon forceps.

Concurrent with biota analyses, measurement of sediment physical and chemical characteristics should be conducted. Aliquots of the homogenized sediment can be analyzed for trace metals, a range of trace organics (e.g. PCBs, pesticides), the extent of oil and grease contamination, particle size distribution, and organic carbon and other measures of nutrient status. The selection of the parameters of interest will necessarily be site specific and depend upon available information on the pollutant source(s).

Data Interpretation

Mortality in test sediment is compared with controls. Control mortality should not exceed 10%. Growth inhibition, indicative of chronic exposure to unfavourable sediment, can be identified by comparing biomass changes of test organisms with those of control organisms. Analysis of variance should be applied to appropriately transformed data (if necessary to achieve a normal distribution), particularly if data are expressed in the form of ratios (e.g. percent reduction in growth of test organisms relative to controls). Similar statistical analyses are used to examine differences in tissue retention of contaminants following the 21 day exposure to sediment that vary in their chemical composition. Significance at $p < 0.05$ is proposed as an indicator of sediment eliciting unacceptable biological responses.

6.0 OTHER ACTIVITIES RELATING TO SEDIMENT BIOASSAY DEVELOPMENT

In conjunction with developing a protocol for the MOE, it has been an advantage to have the opportunity to discuss many of the growing concerns over sediment bioassays with others doing research in this area. The conference on Environmental Risk: Recognition, Assessment and Management, coordinated by the Society of Environmental Toxicology and Chemistry (SETAC) in Pensacola, Florida November 9 to 12, 1987 was of great benefit. Members of the American Society for Testing Materials also held a special session on sediment bioassay protocols. The meetings were of assistance in setting research priorities.

As a consequence of attending SETAC, I was made aware of the research efforts being conducted at North Texas State University (NTSU). After speaking with the coordinator of the NTSU research and the Liaison Officer for this project, it was agreed that visiting the NTSU facilities and gaining access to their voluminous "grey" literature would be a worthwhile investment.

As a direct result of that visit, a strategy for culturing and testing chironomids was prepared, and plans for future research on lab/field comparisons were formulated. Many of the documents acquired for MOE are an excellent source of information that would otherwise have been virtually inaccessible.

Attendance at the first International Conference on Environmental Bioassay Techniques and Their Application, Lancaster England, was most worthwhile. The title alone demonstrates the direct relevance of this meeting to my own and MOE research objectives. In becoming familiar not only with the ongoing research but with the individuals sharing common research goals, the sediment bioassay techniques that are currently recommended for development were substantiated.

Subsequent to the completion of the experiments under the RAP PDF03, additional studies were conducted on bioassay duration and the effects of chemical treatment on sediment toxicity. This work was done in 1989 in support of the Hamilton Harbour Remedial Action Plan and in conjunction with the National Water Research Institute. A paper has been submitted to a peer review journal for consideration.

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TABLE 1: Marine and Freshwater Organisms Used in Acute Toxicity Tests with Sediments

	SPECIES	DURATION (d=days)	APPARATUS	REFERENCE
MARINE				
Amphipods	Rhepoxynius abronius	10d	Static, flowthrough	Swartz et al. 1979
	Rhepoxynius abronius		Static	Swartz et al. 1984
	Parahausterius sp.		Static	Swartz et al. 1985b
	Parahausterius sp.	10d	Static	Shuba et al. 1978
Copepods	Arcartia tonsa	4d	Static	Shuba et al. 1978
	Tigriopus californicus			Shuba et al. 1978
Isopods	Sphaeroma quadridentatum	10d	Static	Shuba et al. 1978
Shrimp	Palaemonetes pugio P. vulgaris	4-15d	Static	Shuba et al. 1978
	Crangon septemspinosa	4-12d	Static	Mcleese & Metcalfe 1980
Polychaetes	Nereis virens	4-12d	Static	Mcleese et al. 1982
	Glycinde picta	10d	Flowthrough	Swartz et al. 1979
Bivalves	Macoma inquinata	10d	Flowthrough	Swartz et al. 1979
	Protothaca staminea	10d	Flowthrough	Swartz et al. 1979
	Mya arenaria	2d	Static	Tsai et al. 1979
Fishes	Fundulus heteroclitus Leiostomus xanthurus	2d	Static	Tsai et al. 1979

TABLE 1: Marine and Freshwater Organisms Used in Acute Toxicity Tests with Sediments (Cont'd)

SPECIES		DURATION (d=days)	APPARATUS	REFERENCE
FRESHWATER				
Water Fleas	Daphnia magna	2d	Recycling	Malueg et al. 1983
	D. magna	2d	Static	Cairns et al. 1984
	D. magna	3d	Recycling	Prater & Hake 1980
	D. magna	3d	Recycling	Prater & Anderson 1977
	D. magna	2d	Recycling Static	USEPA 1988
Amphipods	Hyallela azteca	10d	Static	Nebeker et al. 1984
	Pontoporeia affinis	3d	Static	Nebeker et al. 1986
	Gammarus lacustris	10d	Static	Nebeker et al. 1984
Oligochaetes	unspecified	3d	Static	Reilly et al. 1988
Mayflies	Hexagenia limbata	10d	Static	Lomas & Krantzberg 1988
	Hexagenia limbata	5d	Recycling	Malueg et al. 1983
	Hexagenia limbata	3d	Recycling	Prater & Anderson 1972
	Hexagenia rigida	7d	Static	Friesen et al. 1983
Midges	Chironomus	10d	Static	Nebeker et al. 1984
	Chironomus	10d	Static	Cairns et al. 1984
	Chironomus		Static	Marking et al. 1981
	Chironomus		Static	Gagnon & Beaton 1971
Crayfish	Orconectes virilis	10d	Static Flowthrough	Leonhard 1979
Oligochaetes	Tubifex tubifex			
	Limnodrilus hoffmeisteri	3d	Static	McMurtry 1982

TABLE 1: Marine and Freshwater Organisms Used in Acute Toxicity Tests with Sediments (Cont'd)

SPECIES		DURATION (d=days)	APPARATUS	REFERENCE
FRESHWATER (Cont'd)				
Fish	Micropterus salmoides	4d	Static	Birge et al. 1987
	Carassius auratus			
	Salmo gairdneri			
	Pimephales promelas	10d	Static	Lomas & Krantzberg 1988
	P. promelas	3d	Recycling	Prater & Anderson 1977b
	P. promelas	10d	Flowthrough	Mac et al. 1984
	C. auratus	6-7d	Static	Francis et al. 1984
	M. salmoides			

TABLE 2: Chronic Endpoints Employed for Various Organisms Used in Sediment Bioassays

ENDPOINT	ORGANISM	AUTHOR
Growth Inhibition	Midges, *Chironomus decorus*	Kosalwat & Knight 1987
	C. tentans	Wentsel et al. 1977
	C. tentans	Nebeker et al. 1984
	C. riparis	Powlesland & George 1986
	Paratanytarsus parthenogeneticus	Hatakeyama & Yusuno 1981
	Tanyarsus dissimilis	Anderson et al. 1980
	Oligochaetes, *Tubifex tubifex*,	Wiederholm et al. 1987
	Potamothrix hammoniensis	
	Limnodrilus hoffmeisteri	
	L. udekemianus, *L. claparedeanus*	
	Mayflies, *Hexagenia limbata*	Krantzberg (unpubl. data)
	Amphipods, *Hyallela azteca*	de March 1979
	Fish, *Pimephales promelas*	Brungs et al. 1976
	Salmo gairdneri	Macdonald 1979
	Coregonus clupeaformis	
	P. promela	LeBlanc & Suprenant 1985
Full or Partial Life Cycle Completion	Waterfleas *Daphnia magna*	Nebeker et al. 1986
	D. magna	Biesinger & Christensen 1972
	Midges *C. tentans*	Wentsel et al. 1978
	P. parthenogeneticus	Hatakeyama & Yasuno 1981
	P. parthenogeneticus	LeBlanc & Suprenant 1985
	C. riparis	Powlesland & George 1986
	C. tentans	Nebeker et al. 1988
	C. riparis	Ingersoll et al. 1987

TABLE 2: Chronic Endpoints Employed for Various Organisms Used in Sediment Bioassays (Cont'd)

ENDPOINT	ORGANISM	AUTHOR
Full or Partial Life Cycle (Cont'd)	Amphipods H. azteca	Ingersoll et al. 1987
	Gammarus pseudolimnaeus	Nebeker & Puglisi 1974
	Oligochaetes, Niad	Rodgers (pers. comm.)
	Caddisflies, Clistoronia magnifica	Nebeker et al. 1984b
	Fish Cyprinodon variegatus	Hansen et al. 1987
Burrowing	Oligochaetes, Stylodrilus heringianus, Potamothrix vejdovski, Limnodrilus hoffmeistri	White 1984
	Clams, Protothaca staminea	Phelps et al. 1983
	Amphipods, Rhepoxynius abronius	Swartz et al 1985
Avoidance	Amphipods, Pontoporeia hoyi Gammarus	Gagnon & Beeton 1971
	Midges, Chironomus	Gagnon & Beeton 1971
	C. tentans	Wentsel et al. 1977
	Oligochaetes Tubifex tubifex	McMurtry 1982
	L. hoffmeistri	
	Bivalves Macoma balthica	McGreer 1979
	Fish Coregonus clupeaformis	Scherer 1979
	Salmo gairdneri	
Respiration	Oligochaetes, T. tubifex	Brkovic-Popovic and Popovic 1977
	Crayfish Orconectes virils	Anderson et al. 1978

Table 3. Sample locations and composition of sediment used in bioassays. Numbers refer to sampling Environment Ontario Sampling stations.

SITE	LATITUDE	LONGITUDE	DEPTH (m)	% SAND (>44 µm)	% SILT (42.27-3.73)	% CLAY (3.73-0.17 µm)	pH	% LOI[1]	TOC[2]
TORONTO STP 1	43° 39.26'	79° 18.60'	6.0	79.5	16.2	2.0	7.05	2.2	16.0
TORONTO STP 6	43° 38.76'	79° 18.99'	7.0	58.0	33.2	3.9	6.75	2.2	13.0
ST. MARYS RIVER 3	46° 30.85'	84° 14.90'	1.3	71.6	18.3	1.5	6.66	3.5	19.0
ST. MARYS RIVER 4	46° 31.70'	84° 14.18'	2.8	39.0	49.4	4.2	6.60	12.0	84.0
RICE LAKE 4	44° 16.45'	78° 19.34'	1.4	87.6	9.2	1.4	7.17	3.5	19.0
RICE LAKE 14	44° 08.90'	78° 12.39'	4.0	56.5	33.7	6.0	7.37	23.0	110.0
HONEY HARBOUR	(Southern Georgian Bay)		4.0	15.8	73.3	9.9		7.5	35.0

[1]percent loss on ignition; [2]total organic carbon ($mg.g^{-1}$)

TABLE 4

Contaminant Concentrations in Sediments Used For Bioassays

(All values are in µg/g (dry weight) unless otherwise noted)

SITE	CU	CR	HG	CD	FE	PB	ZN	AS	MN	AL	NI	SOLV. EXTRACT.	PCB (ng/g)
TORONTO STP 1	38	34	0.09	0.76	12000	82	77	2.0	200	4700	9.7	3059	nd[1]
TORONTO STP 6	32	44	0.46	1.10	12000	18	65	1.6	220	5900	11.0	2387	nd
ST. MARYS RIVER 3	21	27	0.07	0.30	13000	25	80	2.6	140	3900	8.0	n/a[2]	n/a
ST. MARYS RIVER 4	86	140	0.30	nd	76000	100	370	15.0	770	8320	28.0	n/a	n/a
RICE LAKE 4	22	21	0.11	nd	10000	16	61	1.1	490	4000	8.9	1900	6140
RICE LAKE 14	63	61	0.32	3.10	24000	91	180	3.9	710	15000	27.0	5770	1160
HONEY HARBOUR	21	44	0.08	1.10	31000	37	110	4.3	900	19000	25.0	n/a	n/a

[1]not detectable; [2]not analyzed

TABLE 5 Effect of Settling Time on Growth of *Hexagenia limbata*
Values in parentheses are standard deviations

MEASUREMENT	SEDIMENT							
	TORONTO STP			RICE LAKE			CONTROL	
	SETTLING TIME							
	5h	24h	120h	5h	24h	120h	5h	24h
Initial Biomass (mg)	22 (3)	19 (4)	19 (1)	16 (2)	20 (4)	17 (2)	22 (2)	23 (3)
Percent Biomass Change (Day 10)	-3 (0.9)	-2 (0.1)	25 (7)	17 (2)	30 (6)	25 (10)	103 (8)	113 (3)
Growth Inhibition (Day 10)[1]	103	102	78	93	73	32	n.a.[2]	n.a.
Percent Mortality (Day 10)	4 (5)	6 (7)	12 (10)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Percent Biomass Change (Day 21)	4 (9)	18 (10)	69 (3)	42 (9)	77 (25)	129 (50)	163 (10)	159 (15)
Growth Inhibition (Day 21)	97	89	57	74	52	19	n.a.	n.a.
Percent Mortality (Day 21)	7 (9)	12 (10)	12 (10)	8 (11)	8 (11)	0 (0)	0 (0)	0 (0)

[1] relative to controls
[2] not applicable

[redacted] of trace organics in oligochaetes as a function of bioassay settling time and exposure duration. All values are $ug.g^{-1}$ unless otherwise noted.

STATION	SETTLING TIME	BIOASSAY DURATION	% LIPID	HCB	HEPTA-CHLOR	HEPTA-CHLOR EPOXIDE	ALDRIN	a-BHC	B-BHC	ALPHA CHLORDANE
RICE LAKE	5	10	0.650	0.013	0.000*	0.000	0.000	0.000	0.000	0.000
TORONTO	5	10	0.750	0.005	0.000	0.000	0.009	0.004	0.180	0.100
CONTROL	5	10	1.290	0.100	0.000	0.000	0.009	0.004	0.000	0.000
RICE LAKE	24	10	1.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	1.290	0.007	0.011	0.000	0.030	0.007	0.000	0.000
RICE LAKE	120	10	0.480	0.004	0.000	0.000	0.009	0.005	0.000	0.000
TORONTO	120	10	0.420	0.000	0.101	0.000	0.000	0.000	0.000	0.000
RICE LAKE	5	21	0.540	0.009	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	5	21	1.020	0.002	0.000	0.000	0.000	0.009	0.000	0.001
RICE LAKE	24	21	0.830	0.002	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	24	21	1.490	0.000	0.000	0.000	0.000	0.015	0.000	0.012
RICE LAKE	120	21	1.080	0.005	0.000	0.000	0.000	0.005	0.000	0.021
TORONTO	120	21	1.580	0.008	0.000	0.000	0.009	0.008	0.000	0.000

*Values listed as 0.000 are below detection.

STATION	SETTLING TIME	BIOASSAY DURATION	GAMMA CHLORDANE	pp-DDE	op-DDT	PCB	LHCB/ LIPID	HEPTACHLOR/ LIPID	HCE/ LIPID	ALDRIN/ LIPID	a-BHC/ LIPID	b-BHC/ LIPID
RICE LAKE	5	10	0.000	0.000	0.000	0.26	0.020	0.000	0.000	0.000	0.000	0.000
TORONTO	5	10	0.000	0.007	0.000	0.00	0.007	0.000	0.000	0.012	0.005	0.240
CONTROL	5	10	0.000	0.000	0.000	0.00	0.078	0.000	0.000	0.002	0.009	0.000
RICE LAKE	24	10	0.000	0.000	0.000	0.66	0.009	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	0.000	0.000	0.000	0.02	0.006	0.009	0.000	0.024	0.006	0.000
RICE LAKE	120	10	0.000	0.000	0.000	0.00	0.008	0.000	0.000	0.019	0.010	0.000
TORONTO	120	10	0.000	0.000	0.000	0.09	0.000	0.240	0.000	0.000	0.000	0.000
RICE LAKE	5	21	0.000	0.000	0.000	0.52	0.006	0.000	0.000	0.000	0.000	0.000
TORONTO	5	21	0.002	0.000	0.000	0.02	0.002	0.000	0.000	0.000	0.009	0.000
RICE LAKE	24	21	0.000	0.000	0.000	0.92	0.002	0.000	0.000	0.000	0.000	0.000
TORONTO	24	21	0.000	0.000	0.057	0.00	0.000	0.000	0.000	0.000	0.010	0.000
RICE LAKE	120	21	0.000	0.000	0.000	0.55	0.005	0.000	0.000	0.000	0.005	0.000
TORONTO	120	21	0.000	0.000	0.000	0.09	0.004	0.000	0.000	0.006	0.004	0.000

STATION	SETTLING TIME	BIOASSAY DURATION	ALPHA CHLORDANE/ LIPID	GAMMA CHLORDANE/ LIPID	pp-DDE LIPID	op-DDT/ LIPID	PCB/ LIPID
RICE LAKE	5	10	0.000	0.000	0.000	0.000	0.994
TORONTO	5	10	0.133	0.000	0.009	0.000	0.000
CONTROL	5	10	0.000	0.000	0.000	0.000	0.000
RICE LAKE	24	10	0.000	0.000	0.000	0.000	0.880
TORONTO	24	10	0.000	0.000	0.000	0.000	0.016
RICE LAKE	120	10	0.000	0.000	0.000	0.000	0.000
TORONTO	120	10	0.000	0.000	0.000	0.000	0.214
RICE LAKE	5	21	0.000	0.000	0.000	0.000	0.963
TORONTO	5	21	0.001	0.002	0.000	0.000	0.020
RICE LAKE	24	21	0.000	0.000	0.000	0.000	0.986
TORONTO	24	21	0.008	0.000	0.000	0.038	0.000
RICE LAKE	120	21	0.020	0.000	0.000	0.000	0.519
TORONTO	120	21	0.000	0.000	0.000	0.000	0.057

Table 7. Trace metals in oligochaeates as a function of bioassay settling time and exposure duration. All values are ug/g

STATION	SETTLING TIME	BIOASSAY DURATION	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Zn
RICE LAKE	5	10	102	3.60	1.31	13.3	73.9	3473	7.5	66.5	0.27	7.8	388
TORONTO	5	10	25	6.20	1.46	11.5	81.1	3846	3.8	55.8	0.13	10.6	475
CONTROL	5	0	56	7.72	1.76	12.2	88.6	4340	3.9	63.7	0.41	4.4	521
RICE LAKE	5	10	112	7.17	1.55	10.0	94.3	4344	6.3	64.1	0.36	13.1	522
TORONTO	24	10	81	7.97	2.13	21.9	111.5	5187	4.7	62.3	0.34	21.4	620
RICE LAKE	24	10	317	4.58	1.09	9.9	74.1	2968	9.8	51.9	0.14	9.7	290
TORONTO	24	10	114	2.78	0.86	8.2	45.9	2060	5.2	26.2	0.15	5.8	205
RICE LAKE	5	21	286	4.58	1.25	7.9	69.2	3253	12.4	54.5	0.17	9.6	342
TORONTO	5	21	39	0.39	0.19	1.7	9.1	506	1.5	5.8	0.00	1.8	53
RICE LAKE	24	21	90	3.21	0.73	5.2	44.1	2165	6.3	32.8	0.15	5.9	252
TORONTO	24	21	167	4.37	1.49	7.0	58.9	2968	7.8	34.2	0.15	5.4	361
RICE LAKE	120	21	175	3.09	0.66	6.4	40.5	1832	7.2	31.9	0.09	5.3	201
TORONTO	120	21	1114	5.08	1.19	19.1	60.3	4576	26.4	77.9	0.11	8.5	259
CONTROL	5	21	2530	6.86	1.25	15.8	62.2	6859	11.5	172.0	0.10	13.8	348

TABLE 8: Effect of Settling Time on Growth of Pimephales promelas at two densities. Values in parentheses are standard deviations

	SEDIMENT															
	TORONTO STP						ST. MARY'S RIVER						CONTROL			
	SETTLING TIME															
	5h		24h		120h		5h		24h		120h		5h		24h	
	DENSITY															
	10[1]	15[2]	10	15	10	15	10	15	10	15	10	15	10	15	10	15
Initial Biomass (mg)	449 (18)	480 (15)	541 (35)	512 (18)	541 (30)	550 (10)	473 (23)	482 (43)	528 (58)	530 (44)	517 (40)	499 (23)	497 (34)	499 (22)	503 (26)	499 (9)
Percent Biomass Change (Day 10)	-14 (2)	-21 (0.6)	-24 (0.1)	-16 (0.4)	-4 (0.2)	-15 (0.1)	-19 (0.5)	-16 (0.1)	-10 (0.8)	-17 (0.7)	-7 (0.1)	-5 (0.2)	-4 (0)	-3 (0)	-3 (0)	-6 (0)
Growth Inhibition[3]	250	600	700	167	0	230	375	433	233	278	100	11	n.a.[4]	n.a.	n.a.	n.a.
Percent Biomass Change (Day 21)	-23 (1)	-30 (2)	-35 (3)	-32 (4)	-13 (0.7)	-20 (0.4)	-26 (1)	-37 (0.9)	-18 (1.1)	-23 (0.1)	-10 (0.1)	-12 (0.3)	-8 (0)	-6 (0.1)	-9 (0.1)	-9 (0.1)
Growth Inhibition	187	400	289	256	53	167	225	512	100	156	10	33	n.a.	n.a.	n.a.	n.a.

[1] 10 individuals; [2] 15 individuals; [3] relative to controls; n.a. not applicable

Table 9. Trace metals in fathead minnows as a function of bioassay settling time, exposure duration, organism density and gut clearance. All values are $ug.g^{-1}$ unless otherwise noted.

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	Al	As	Cd	Cr	Cu	Fe	Pb
TORONTO	5	10	10	no	876	7.34	0.55	34.7	245	2205	8.93
TORONTO	5	10	10	no	1871	6.26	1.19	59.7	300	5636	28.92
TORONTO	5	10	10	no	2045	8.98	1.14	54.0	303	5189	47.84
TORONTO	5	10	15	no	413	5.89	0.22	22.0	216	1189	4.49
TORONTO	5	10	15	no	2087	5.97	1.03	41.2	279	6077	28.28
ST. MARY'S	5	10	10	no	1358	22.76	0.50	39.9	255	5889	30.20
ST. MARY'S	5	10	10	no	1801	14.50	0.53	30.4	255	6184	35.91
ST. MARY'S	5	10	15	no	1204	24.58	0.25	24.6	188	5413	25.93
ST. MARY'S	5	10	15	no	873	14.99	0.25	28.7	200	3741	18.56
ST. MARY'S	5	10	15	no	1059	7.15	0.43	29.7	225	4912	22.42
TORONTO	5	10	15	yes	1817	19.20	0.27	59.2	690	6569	25.92
TORONTO	5	10	15	yes	4264	14.90	0.97	75.8	429	9660	36.93
TORONTO	24	10	10	no	2859	3.53	1.76	75.3	396	8918	37.73
TORONTO	24	10	10	no	1323	15.19	0.46	31.1	269	7782	24.78
TORONTO	24	10	15	no	257	15.94	0.13	13.8	182	819	5.97
TORONTO	24	10	15	no	429	17.86	0.17	22.9	295	1104	3.25
ST. MARY'S	5	10	15	yes	1851	17.79	0.82	56.4	346	7788	37.83
ST. MARY'S	5	10	15	yes	2798	22.94	1.15	62.1	488	12806	56.71
ST. MARY'S	24	10	10	no	980	12.77	0.59	28.9	225	4156	21.01
ST. MARY'S	24	10	10	no	1310	7.83	0.49	31.8	238	5242	26.96
ST. MARY'S	24	10	10	no	1425	9.08	0.49	28.4	244	5876	29.20
ST. MARY'S	24	10	15	no	2071	11.21	0.84	43.2	294	9118	38.85
ST. MARY'S	24	10	15	no	732	20.89	0.25	21.8	214	2914	14.09
TORONTO	24	10	15	yes	233	34.89	0.13	15.6	183	617	2.80
TORONTO	24	10	15	yes	406	21.86	0.17	18.8	256	1059	4.23
ST. MARY'S	24	10	10	yes	589	17.02	0.24	20.5	175	2532	11.20
ST. MARY'S	24	10	15	yes	363	28.06	0.22	16.8	183	1143	5.47
TORONTO	120	10	10	no	3870	11.65	1.56	63.0	283	11102	45.57
TORONTO	120	10	10	no	2494	6.86	1.70	49.4	195	7022	37.03

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	Al	As	Cd	Cr	Cu	Fe	Pb
TORONTO	120	10	15	no	1148	3.94	0.51	24.7	192	2907	16.54
TORONTO	120	10	15	no	3433	7.14	2.17	70.9	255	10826	68.59
ST. MARY'S	120	10	10	no	1124	9.06	0.56	24.9	195	4661	31.75
ST. MARY'S	120	10	10	no	963	10.97	0.54	19.9	209	3798	28.99
ST. MARY'S	120	10	15	no	1623	7.47	0.82	27.1	183	6630	41.33
CONTROL	24	10	15	no	1367	12.43	0.59	24.1	182	5749	39.39
CONTROL	24	10	10	no	1598	9.61	0.94	17.2	180	2847	3.51
TORONTO	120	10	15	no	1541	8.16	0.24	17.9	201	2500	5.85
TORONTO	120	10	15	yes	668	6.93	0.84	21.7	175	2221	12.13
TORONTO	120	10	15	yes	594	10.18	0.28	18.7	161	1601	7.18
ST. MARY'S	120	10	15	yes	741	16.12	0.51	16.9	170	1982	9.29
ST. MARY'S	120	10	15	yes	528	29.58	0.29	14.5	143	1883	13.67
CONTROL	24	10	15	yes	665	32.86	0.32	14.5	130	2741	15.57
TORONTO	5	21	10	no	863	38.01	0.91	14.4	160	1713	3.85
TORONTO	24	21	10	no	2635	30.01	2.23	58.8	328	7654	50.91
TORONTO	5	21	15	no	2963	21.62	2.20	55.9	311	8905	49.85
TORONTO	5	21	15	no	979	27.89	0.63	24.6	297	2574	13.72
ST. MARY'S	5	21	10	no	2012	12.56	1.49	49.5	235	5771	36.82
ST. MARY'S	5	21	10	no	1980	32.98	0.71	37.9	254	7721	48.46
ST. MARY'S	5	21	15	no	2097	22.04	0.86	32.9	249	8267	47.90
ST. MARY'S	5	21	15	no	1266	17.22	0.56	31.1	204	4922	31.42
ST. MARY'S	5	21	15	no	1839	17.66	0.88	30.9	226	7252	52.99
TORONTO	24	21	10	no	1991	15.79	0.54	24.3	208	5586	32.05
TORONTO	24	21	10	no	1365	39.26	0.80	24.9	202	3403	24.23
TORONTO	24	21	15	no	1104	20.23	0.52	20.7	242	2851	18.27
ST. MARY'S	24	21	10	no	1332	36.26	0.74	30.3	278	3152	10.98
ST. MARY'S	24	21	10	no	1157	27.22	0.41	17.2	161	5768	51.71
ST. MARY'S	24	21	15	no	1477	29.98	0.47	29.6	247	6875	37.40
ST. MARY'S	5	21	10	no	1619	27.26	0.45	28.3	222	7718	44.25
TORONTO	120	21	15	no	1371	15.16	0.42	26.8	341	5892	32.50
TORONTO	120	21	15	no	1016	29.17	0.36	16.2	137	2769	13.45
TORONTO	120	21	10	no	629	20.93	0.99	16.8	151	1684	16.71
					2344	29.56	0.91	32.1	148	6047	35.95

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	Al	As	Cd	Cr	Cu	Fe	Pb
TORONTO	120	21	10	no	1274	24.88	0.42	19.9	116	3414	25.07
ST. MARY'S	120	21	10	no	557	26.85	0.18	12.8	111	2810	12.88
ST. MARY'S	120	21	10	no	587	10.40	0.21	15.4	210	2235	12.78
ST. MARY'S	120	21	10	no	1360	23.28	0.43	23.4	200	6444	32.74
ST. MARY'S	120	21	15	no	1565	22.44	0.49	27.4	206	7155	32.86
ST. MARY'S	24	21	15	no	1422	31.39	0.44	22.5	168	6852	31.18
ST. MARY'S	5	21	10	yes	429	29.54	0.24	6.9	189	1946	6.81
CONTROL	120	21	10	yes	751	17.40	0.59	21.1	236	3092	14.40
CONTROL	120	21	15	no	1922	16.55	0.46	19.4	108	3232	8.26
TORONTO	120	21	15	no	1698	23.03	0.45	15.8	125	2920	4.46
TORONTO	120	21	15	yes	329	5.58	0.19	12.0	110	772	3.85
ST. MARY'S	120	21	15	yes	1172	25.24	0.68	22.9	158	3069	15.17
ST. MARY'S	120	21	15	yes	516	19.56	0.51	15.9	181	2067	8.26
CONTROL	120	21	15	yes	512	32.82	0.25	13.1.	128	2532	8.72
					1747	9.96	0.59	16.9	178	2934	5.80

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	Mn	Hg	Ni	Zn
TORONTO	5	10	10	no	57.95	4.22	8.86	2154
TORONTO	5	10	10	no	101.25	4.90	11.82	2272
TORONTO	5	10	10	no	106.30	5.68	19.95	2539
TORONTO	5	10	15	no	36.17	4.76	9.97	2085
ST. MARY'S	5	10	15	no	111.06	4.04	14.73	2176
ST. MARY'S	5	10	10	no	125.85	4.20	18.35	2149
ST. MARY'S	5	10	10	no	129.11	3.63	20.34	1973
ST. MARY'S	5	10	15	no	108.96	3.58	14.56	1699
ST. MARY'S	5	10	15	no	82.29	3.86	9.88	1410
TORONTO	5	10	15	yes	92.77	3.76	16.25	1864
TORONTO	5	10	15	yes	170.34	5.75	19.74	4811
TORONTO	24	10	10	no	239.54	7.07	48.78	3075
TORONTO	24	10	10	no	152.20	5.71	28.96	3099
TORONTO	24	10	15	no	79.88	6.94	9.86	2643
TORONTO	24	10	15	no	34.69	4.79	3.67	1701
ST. MARY'S	5	10	15	yes	49.06	7.84	10.99	2405
ST. MARY'S	5	10	15	yes	163.38	7.07	19.00	2979
ST. MARY'S	24	10	10	no	255.55	9.18	22.24	4644
ST. MARY'S	24	10	10	no	97.10	4.94	12.75	2144
ST. MARY'S	24	10	10	no	114.71	4.33	12.69	1881
ST. MARY'S	24	10	15	no	125.83	4.41	15.23	1927
ST. MARY'S	24	10	15	no	190.44	5.51	19.78	2568
TORONTO	24	10	15	no	70.80	5.07	11.46	1838.
TORONTO	24	10	15	yes	26.89	4.79	4.74	1670.
ST. MARY'S	24	10	10	yes	34.48	7.32	5.84	2223.
ST. MARY'S	24	10	15	yes	59.31	5.06	7.27	1582.
TORONTO	120	10	10	no	33.39	5.04	6.11	1525.
TORONTO	120	10	10	no	171.88	4.94	21.56	1803.
					101.59	6.06	22.30	1317

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	Mn	Hg	Ni	Zn
TORONTO	120	10	15	no	57.93	5.49	6.56	1450
TORONTO	120	10	15	no	151.75	4.55	18.06	1953
ST. MARY'S	120	10	10	no	102.66	3.88	8.79	1409
ST. MARY'S	120	10	10	no	89.09	3.79	10.50	1650
ST. MARY'S	120	10	15	no	142.97	3.25	18.59	1586
ST. MARY'S	120	10	15	no	129.85	2.80	11.58	1481
CONTROL	24	10	10	no	112.66	4.68	10.26	1583
CONTROL	24	10	15	no	119.67	4.86	8.75	1592
TORONTO	120	10	15	yes	31.99	3.01	11.13	1503
TORONTO	120	10	15	yes	27.52	2.85	6.58	1285
TORONTO	120	10	15	yes	37.84	3.31	4.78	1451
ST. MARY'S	120	10	15	yes	44.57	2.84	5.80	1534
ST. MARY'S	120	10	15	yes	61.86	3.24	5.96	1426
CONTROL	24	10	15	yes	62.86	5.44	7.77	1632
TORONTO	5	21	10	no	131.00	7.04	19.09	2421
TORONTO	24	21	10	no	155.25	5.99	22.89	2538
TORONTO	5	21	15	no	59.38	5.70	9.10	2102
TORONTO	5	21	15	no	98.30	5.31	17.85	2417
ST. MARY'S	5	21	10	no	171.50	5.35	16.29	2124
ST. MARY'S	5	21	10	no	177.14	5.41	17.99	2236
ST. MARY'S	5	21	15	no	106.26	4.92	9.72	1862
ST. MARY'S	5	21	15	no	159.29	6.16	22.31	2108
TORONTO	24	21	10	no	121.36	5.59	12.52	1813
TORONTO	24	21	10	no	64.87	3.46	8.89	1810
TORONTO	24	21	15	no	57.35	4.28	8.49	2036
ST. MARY'S	24	21	10	no	88.04	1.65	16.94	2128
ST. MARY'S	24	21	10	no	112.00	2.83	12.04	1572
ST. MARY'S	24	21	15	no	136.17	4.07	18.18	2381
ST. MARY'S	5	21	10	no	158.34	2.97	16.90	1638
TORONTO	120	21	15	no	124.13	4.12	13.52	1928
TORONTO	120	21	15	no	51.66	2.51	8.68	1230
TORONTO	120	21	10	no	31.88	2.96	5.08	1420
					116.29	2.04	13.56	1424

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	Mn	Hg	Ni	Zn
TORONTO	120	21	10	no	60.57	3.04	8.11	1327
ST. MARY'S	120	21	10	no	59.64	2.78	5.29	1210
ST. MARY'S	120	21	10	no	56.06	2.59	8.85	1364
ST. MARY'S	120	21	15	no	127.36	4.15	17.10	1619
ST. MARY'S	120	21	15	no	144.10	3.23	13.10	1526
ST. MARY'S	24	21	15	yes	133.97	1.88	14.57	1421
ST. MARY'S	5	21	10	yes	52.30	4.14	-13.34	1545
CONTROL	120	21	10	no	71.50	3.50	10.73	1941
CONTROL	120	21	15	no	130.63	2.06	8.95	1150
TORONTO	120	21	15	yes	119.84	3.09	7.50	1328
TORONTO	120	21	15	yes	14.65	1.49	3.82	856
ST. MARY'S	120	21	15	yes	70.02	3.13	13.80	1514
ST. MARY'S	120	21	15	yes	47.63	3.09	7.85	1666
CONTROL	120	21	15	yes	51.34	2.58	4.84	1538
					112.14	2.29	12.30	1498

Table 10. Trace organics in fathead minnows as a function of bioassay settling time, exposure duration, organism density and gut clearance. All values are $ug.g^{-1}$ unless otherwise noted.

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	% LIPID	HCB	HEPTA-CHLOR	HEPTA-CHLOR EPOXIDE	ALDRIN	a-BHC	B-BHC
TORONTO	5	10	10	NO	8.590	0.071	0.000*	0.021	0.000	0.000	0.000
TORONTO	5	10	10	NO	9.680	0.091	0.000	0.010	0.000	0.000	0.000
TORONTO	5	10	15	NO	8.570	0.008	0.000	0.000	0.000	0.008	0.000
TORONTO	5	10	15	NO	8.940	0.008	0.000	0.001	0.000	0.000	0.000
ST. MARY'S	5	10	10	NO	8.300	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	10	NO	8.080	0.001	0.000	0.000	0.000	0.000	0.025
ST. MARY'S	5	10	15	NO	8.290	0.009	0.000	0.005	0.000	0.000	0.110
ST. MARY'S	5	10	15	NO	8.590	0.000	0.000	0.002	0.000	0.001	0.000
TORONTO	5	10	15	YES	8.180	0.000	0.005	0.000	0.000	0.000	0.010
TORONTO	5	10	15	YES	8.540	0.000	0.007	0.000	0.000	0.000	0.000
TORONTO	24	10	10	NO	9.470	0.000	0.005	0.000	0.001	0.000	0.000
TORONTO	24	10	10	NO	10.970	0.000	0.000	0.004	0.000	0.000	0.000
TORONTO	24	10	15	NO	10.690	0.002	0.009	0.003	0.000	0.000	0.011
TORONTO	24	10	15	NO	9.310	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	15	YES	7.760	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	15	YES	7.920	0.002	0.010	0.003	0.000	0.010	0.000
ST. MARY'S	24	10	10	NO	10.260	0.000	0.007	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	10	NO	10.020	0.001	0.001	0.000	0.002	0.002	0.000
ST. MARY'S	24	10	15	NO	8.290	0.003	0.000	0.000	0.000	0.002	0.000
ST. MARY'S	24	10	15	NO	9.950	0.004	0.003	0.004	0.002	0.003	0.000
TORONTO	24	10	15	NO	11.450	0.000	0.003	0.000	0.000	0.005	0.000
TORONTO	24	10	15	YES	11.120	0.000	0.003	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	10	YES	9.530	0.004	0.003	0.000	0.000	0.003	0.000
ST. MARY'S	24	10	15	YES	9.860	0.003	0.000	0.000	0.000	0.003	0.000
TORONTO	120	10	10	NO	8.560	0.000	0.000	0.000	0.002	0.005	0.000
TORONTO	120	10	10	NO	7.570	0.005	0.000	0.000	0.000	0.000	0.000
TORONTO	120	10	15	NO	6.930	0.004	0.002	0.007	0.000	0.001	0.000
TORONTO	120	10	15	NO	8.030	0.005	0.000	0.000	0.000	0.002	0.000
ST. MARY'S	120	10	10	NO	7.750	0.003	0.000	0.000	0.003	0.010	0.000

* Values listed as 0.000 are below detection

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	% LIPID	HCB	HEPTA-CHLOR	HEPTA-CHLOR EPOXIDE	ALDRIN	a-BHC	B-BHC
ST. MARY'S	120	10	10	NO	5.450	0.003	0.004	0.001	0.000	0.000	0.000
ST. MARY'S	120	10	15	NO	7.510	0.003	0.004	0.000	0.000	0.003	0.000
ST. MARY'S	120	10	15	NO	14.430	0.000	0.008	0.000	0.000	0.000	0.000
CONTROL	24	10	10	NO	4.870	0.003	0.004	0.002	0.000	0.000	0.000
CONTROL	24	10	15	NO	8.270	0.005	0.009	0.000	0.000	0.010	0.000
TORONTO	120	10	15	YES	9.790	0.007	0.000	0.000	0.002	0.000	0.014
TORONTO	120	10	15	YES	7.820	0.005	0.003	0.003	0.000	0.000	0.000
ST. MARY'S	120	10	15	YES	5.810	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	15	YES	7.870	0.002	0.000	0.000	0.000	0.000	0.000
CONTROL	24	10	15	YES	4.430	0.001	0.002	0.000	0.001	0.000	0.000
TORONTO	5	21	10	NO	4.840	0.004	0.000	0.000	0.002	0.002	0.000
TORONTO	24	21	10	NO	7.160	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	5	21	15	NO	7.340	0.000	0.000	0.000	0.004	0.000	0.000
TORONTO	5	21	15	NO	8.090	0.000	0.000	0.001	0.000	0.000	0.000
ST. MARY'S	5	21	10	NO	7.010	0.004	0.003	0.000	0.000	0.004	0.000
ST. MARY'S	5	21	10	NO	8.090	0.000	0.000	0.000	0.000	0.005	0.000
ST. MARY'S	5	21	15	NO	8.850	0.010	0.000	0.000	0.005	0.004	0.000
ST. MARY'S	5	21	15	NO	5.560	0.000	0.000	0.000	0.000	0.005	0.000
TORONTO	24	21	10	NO	8.180	0.005	0.000	0.000	0.006	0.003	0.000
TORONTO	24	21	10	NO	8.180	0.004	0.012	0.000	0.000	0.000	0.032
TORONTO	24	21	15	NO	6.170	0.008	0.011	0.000	0.000	0.006	0.000
ST. MARY'S	24	21	10	NO	7.990	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	10	NO	6.950	0.000	0.010	0.000	0.000	0.000	0.000
ST. MARY'S	5	21	10	NO	13.120	0.000	0.000	0.000	0.001	0.001	0.000
TORONTO	120	21	15	NO	7.360	0.007	0.000	0.000	0.000	0.003	0.000
TORONTO	120	21	15	NO	5.640	0.007	0.000	0.000	0.000	0.002	0.000
TORONTO	120	21	10	NO	5.140	0.004	0.004	0.000	0.000	0.002	0.000
ST. MARY'S	120	21	10	NO	7.300	0.000	0.000	0.000	0.000	0.004	0.000
ST. MARY'S	120	21	10	NO	8.930	0.004	0.005	0.000	0.000	0.004	0.000
ST. MARY'S	120	21	15	NO	8.080	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	21	15	NO	6.520	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	15	YES	7.890	0.000	0.000	0.004	0.002	0.000	0.000
					9.490	0.000	0.000	0.000	0.004	0.008	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	% LIPID	HCB	HEPTA-CHLOR	HEPTA-CHLOR EPOXIDE	ALDRIN	a-BHC	B-BHC
ST. MARY'S	5	21	10	YES	8.090	0.000	0.018	0.000	0.000	0.011	0.000
CONTROL	120	21	10	NO	11.120	0.004	0.000	0.000	0.000	0.004	0.000
CONTROL	120	21	15	NO	10.130	0.004	0.000	0.000	0.000	0.009	0.000
TORONTO	120	21	15	YES	6.000	0.009	0.014	0.000	0.000	0.000	0.000
TORONTO	120	21	15	YES	9.250	0.000	0.000	0.000	0.000	0.007	0.000
ST. MARY'S	120	21	15	YES	3.080	0.005	0.004	0.000	0.000	0.002	0.000
ST. MARY'S	120	21	15	YES	7.970	0.004	0.004	0.000	0.000	0.003	0.000
CONTROL	120	21	15	YES	6.700	0.000	0.000	0.000	0.000	0.000	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	HCB/ LIPID	HEPTA CHLOR/ LIPID	HCD/ LIPID	ALDRIN/ LIPID	a-BHC/ LIPID	b-BHC/ LIPID	ALPHA CHLORDANE/ LIPID
TORONTO	5	10	10	NO	0.008	0.000	0.002	0.000	0.000	0.000	0.001
TORONTO	5	10	10	NO	0.003	0.000	0.001	0.000	0.000	0.000	0.001
TORONTO	5	10	15	NO	0.001	0.000	0.000	0.000	0.001	0.000	0.000
TORONTO	5	10	15	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	10	NO	0.000	0.000	0.000	0.000	0.000	0.003	0.000
ST. MARY'S	5	10	15	NO	0.001	0.000	0.001	0.000	0.000	0.013	0.001
ST. MARY'S	5	10	15	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	5	10	15	YES	0.000	0.001	0.000	0.000	0.000	0.001	0.000
TORONTO	5	10	15	YES	0.000	0.001	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	10	NO	0.000	0.001	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	15	NO	0.000	0.001	0.000	0.000	0.000	0.001	0.000
TORONTO	24	10	15	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	15	YES	0.000	0.001	0.000	0.000	0.001	0.000	0.000
ST. MARY'S	24	10	10	NO	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	15	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	15	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	24	10	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	10	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	120	10	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	120	10	10	NO	0.001	0.000	0.000	0.000	0.001	0.000	0.001
TORONTO	120	10	15	NO	0.001	0.000	0.001	0.000	0.000	0.000	0.001
TORONTO	120	10	15	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	10	NO	0.000	0.000	0.000	0.000	0.001	0.000	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	HCB/ LIPID	HEPTA CHLOR/ LIPID	HCD/ LIPID	ALDRIN/ LIPID	a-BHC/ LIPID	b-BHC/ LIPID	ALPHA CHLORDANE/ LIPID
ST. MARY'S	120	10	10	NO	0.001	0.001	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	15	NO	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	15	NO	0.000	0.001	0.000	0.000	0.000	0.000	0.000
CONTROL	24	10	10	NO	0.001	0.001	0.000	0.000	0.000	0.000	0.001
CONTROL	24	10	15	NO	0.001	0.001	0.000	0.000	0.001	0.000	0.000
TORONTO	120	10	15	YES	0.001	0.000	0.000	0.000	0.000	0.001	0.001
TORONTO	120	10	15	YES	0.001	0.000	0.000	0.000	0.000	0.000	0.001
ST. MARY'S	120	10	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.001
CONTROL	24	10	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	5	21	10	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.001
TORONTO	24	21	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.001
TORONTO	5	21	15	NO	0.000	0.000	0.000	0.001	0.000	0.000	0.000
TORONTO	5	21	15	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.001
ST. MARY'S	5	21	10	NO	0.001	0.000	0.000	0.000	0.001	0.000	0.001
ST. MARY'S	5	21	10	NO	0.000	0.000	0.000	0.000	0.001	0.000	0.001
ST. MARY'S	5	21	15	NO	0.001	0.000	0.000	0.001	0.001	0.000	0.000
ST. MARY'S	5	21	15	NO	0.000	0.000	0.000	0.000	0.001	0.000	0.000
TORONTO	24	21	10	NO	0.001	0.000	0.000	0.001	0.000	0.000	0.000
TORONTO	24	21	10	NO	0.000	0.001	0.000	0.000	0.000	0.004	0.000
TORONTO	24	21	15	NO	0.001	0.002	0.000	0.000	0.001	0.000	0.000
ST. MARY'S	24	21	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	10	NO	0.000	0.001	0.000	0.000	0.000	0.000	0.001
ST. MARY'S	5	21	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	120	21	15	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.001
TORONTO	120	21	15	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000
TORONTO	120	21	10	NO	0.001	0.001	0.000	0.000	0.000	0.000	0.000
TORONTO	120	21	10	NO	0.000	0.000	0.000	0.000	0.001	0.000	0.000
ST. MARY'S	120	21	10	NO	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	21	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	120	21	15	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.001
ST. MARY'S	120	21	15	NO	0.000	0.000	0.001	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	15	YES	0.000	0.000	0.000	0.000	0.001	0.000	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	HCB/ LIPID	HEPTA CHLOR/ LIPID	HCD/ LIPID	ALDRIN/ LIPID	a-BHC/ LIPID	b-BHC/ LIPID	ALPHA CHLORDANE/ LIPID
ST. MARY'S	5	21	10	YES	0.000	0.002	0.000	0.000	0.001	0.000	0.000
CONTROL	120	21	10	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CONTROL	120	21	15	NO	0.000	0.000	0.000	0.000	0.001	0.000	0.000
TORONTO	120	21	15	YES	0.002	0.002	0.000	0.000	0.000	0.000	0.000
TORONTO	120	21	15	YES	0.000	0.000	0.000	0.000	0.001	0.000	0.001
ST. MARY'S	120	21	15	YES	0.002	0.001	0.000	0.000	0.001	0.000	0.001
ST. MARY'S	120	21	15	YES	0.001	0.001	0.000	0.000	0.000	0.000	0.001
CONTROL	120	21	15	YES	0.000	0.000	0.000	0.000	0.000	0.000	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	GAMMA CHLORDANE/ LIPID	pp-DDE/ LIPID	op-DDT/ LIPID	PCB/ LIPID
TORONTO	5	10	10	NO	0.003	0.002	0.000	0.051
TORONTO	5	10	10	NO	0.001	0.002	0.000	0.000
TORONTO	5	10	15	NO	0.000	0.000	0.000	0.005
TORONTO	5	10	15	NO	0.000	0.000	0.000	0.009
ST. MARY'S	5	10	10	NO	0.001	0.000	0.000	0.006
ST. MARY'S	5	10	10	NO	0.000	0.000	0.000	0.000
ST. MARY'S	5	10	15	NO	0.000	0.002	0.000	0.000
ST. MARY'S	5	10	15	NO	0.000	0.000	0.000	0.002
TORONTO	5	10	15	YES	0.000	0.000	0.000	0.000
TORONTO	5	10	15	YES	0.000	0.000	0.000	0.000
TORONTO	24	10	10	NO	0.001	0.000	0.000	0.008
TORONTO	24	10	10	NO	0.000	0.000	0.000	0.008
TORONTO	24	10	15	NO	0.000	0.000	0.000	0.011
TORONTO	24	10	15	NO	0.000	0.000	0.000	0.006
ST. MARY'S	5	10	15	YES	0.000	0.000	0.000	0.066
ST. MARY'S	5	10	15	YES	0.000	0.001	0.000	0.000
ST. MARY'S	24	10	10	NO	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	10	NO	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	15	NO	0.000	0.000	0.006	0.000
ST. MARY'S	24	10	15	NO	0.000	0.002	0.000	0.000
TORONTO	24	10	15	NO	0.000	0.000	0.000	0.000
TORONTO	24	10	15	YES	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	10	YES	0.000	0.000	0.000	0.000
ST. MARY'S	24	10	15	YES	0.000	0.002	0.000	0.000
TORONTO	120	10	10	NO	0.000	0.009	0.000	0.001
TORONTO	120	10	10	NO	0.000	0.002	0.000	0.000
TORONTO	120	10	15	NO	0.000	0.002	0.000	0.000
TORONTO	120	10	15	NO	0.000	0.002	0.000	0.000
ST. MARY'S	120	10	10	NO	0.000	0.000	0.000	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	GAMMA CHLORDANE/ LIPID	pp-DDE/ LIPID	op-DDT/ LIPID	PCB/ LIPID
ST. MARY'S	120	10	10	NO	0.000	0.001	0.001	0.000
ST. MARY'S	120	10	15	NO	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	15	NO	0.000	0.000	0.000	0.000
CONTROL	24	10	10	NO	0.000	0.001	0.000	0.000
CONTROL	24	10	15	NO	0.000	0.002	0.000	0.000
TORONTO	120	10	15	YES	0.000	0.002	0.000	0.000
TORONTO	120	10	15	YES	0.000	0.002	0.000	0.000
ST. MARY'S	120	10	15	YES	0.000	0.000	0.000	0.000
ST. MARY'S	120	10	15	YES	0.000	0.002	0.000	0.000
CONTROL	24	10	15	YES	0.001	0.002	0.000	0.000
TORONTO	5	21	10	NO	0.001	0.000	0.027	0.000
TORONTO	24	21	10	NO	0.001	0.003	0.000	0.000
TORONTO	5	21	15	NO	0.000	0.000	0.000	0.000
TORONTO	5	21	15	NO	0.000	0.000	0.000	0.000
ST. MARY'S	5	21	10	NO	0.001	0.000	0.000	0.000
ST. MARY'S	5	21	10	NO	0.000	0.002	0.000	0.000
ST. MARY'S	5	21	15	NO	0.000	0.000	0.000	0.016
ST. MARY'S	5	21	15	NO	0.000	0.000	0.000	0.002
TORONTO	24	21	10	NO	0.000	0.000	0.000	0.000
TORONTO	24	21	10	NO	0.000	0.000	0.000	0.000
TORONTO	24	21	15	NO	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	10	NO	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	10	NO	0.000	0.003	0.000	0.000
ST. MARY'S	5	21	10	NO	0.000	0.002	0.000	0.000
TORONTO	120	21	15	NO	0.001	0.003	0.000	0.000
TORONTO	120	21	15	NO	0.001	0.000	0.000	0.000
TORONTO	120	21	10	NO	0.001	0.003	0.000	0.000
TORONTO	120	21	10	NO	0.001	0.000	0.001	0.000
ST. MARY'S	120	21	10	NO	0.001	0.003	0.002	0.000
ST. MARY'S	120	21	10	NO	0.001	0.002	0.000	0.000
ST. MARY'S	120	21	15	NO	0.001	0.002	0.000	0.000
ST. MARY'S	120	21	15	NO	0.000	0.000	0.000	0.000
ST. MARY'S	24	21	15	YES	0.001	0.003	0.000	0.000

STATION	SETTLING TIME (hr)	BIOASSAY DURATION (day)	NUMBER OF FISH	GUT CLEARANCE	GAMMA CHLORDANE/ LIPID	pp-DDE/ LIPID	op-DDT/ LIPID	PCB/ LIPID
ST. MARY'S	5	21	10	YES	0.000	0.000	0.000	0.001
CONTROL	120	21	10	NO	0.000	0.000	0.000	0.001
CONTROL	120	21	15	NO	0.000	0.000	0.000	0.000
TORONTO	120	21	15	YES	0.000	0.000	0.000	0.000
TORONTO	120	21	15	YES	0.001	0.002	0.000	0.000
ST. MARY'S	120	21	15	YES	0.001	0.005	0.000	0.000
ST. MARY'S	120	21	15	YES	0.000	0.001	0.000	0.000
CONTROL	120	21	15	YES	0.000	0.000	0.000	0.000

TABLE 11: Effect of feeding on growth of Pimephales promelas exposed to clean and contaminated sediments. Values in parentheses are standard deviations

MEASUREMENT	SEDIMENT					
	RICE LAKE		ST. MARYS		CONTROL	
	TREATMENT					
	FED	UNFED	FED	UNFED	FED	UNFED
Initial Biomass (mg)	392 (47)	366 (79)	353 (58)	332 (32)	344 (23)	368 (21)
Percent Biomass Change	-14 (2)	-11 (2)	-18 (2)	-21 (3)	5 (0.2)	-9 (0.4)
Growth[1] Inhibition	380	22	460	133	n.a.[2]	n.a.

[1] relative to controls

[2] not applicable

Table 12. Trace metals in fathead minnows as a function of feeding and gut clearance. All values are $ug.g^{-1}$ unless otherwise noted.

STATION	FOOD	PURGE	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Zn
ALGOMA	NO	NO	2934	23.19	0.38	31.0	246	4754	13.90	206.48	2.10	14.69	1973
RICE LAKE	NO	NO	3224	10.19	1.99	32.2	225	6069	30.18	250.47	2.45	14.86	1758
RICE LAKE	NO	NO	2496	15.24	1.59	29.7	204	4668	26.57	196.66	2.11	9.06	1700
ST. MARY'S	NO	NO	1252	20.10	0.70	22.5	210	5387	21.19	81.36	2.32	8.69	1802
ST. MARY'S	NO	NO	968	17.01	0.48	22.2	176	3283	10.95	52.66	1.40	11.45	1780
TORONTO	NO	NO	4184	19.21	0.76	20.9	203	7544	10.99	285.29	2.88	9.46	1688
TORONTO	NO	NO	3875	15.72	0.89	21.7	176	6862	11.92	285.42	2.59	12.71	1481
ALGOMA	NO	NO	438	3.24	0.06	4.6	45	892	1.99	75.40	0.58	1.56	355
RICE LAKE	NO	YES	1486	11.59	1.02	21.5	164	2718	16.60	107.55	2.04	11.60	1539
RICE LAKE	NO	YES	1945	17.07	1.40	30.9	240	3626	20.57	130.65	3.20	13.58	1855
ST. MARY'S	NO	YES	947	11.04	0.46	21.2	205	3732	12.64	52.81	2.35	6.50	1887
ST. MARY'S	NO	YES	899	19.99	0.47	18.7	206	3369	12.44	51.45	2.17	3.74	1678
TORONTO	NO	YES	1981	8.35	1.05	21.5	200	3525	4.25	140.19	2.22	13.60	1851
TORONTO	NO	YES	1556	8.95	0.56	17.2	169	2867	4.99	106.35	2.13	5.92	1598
RICE LAKE	YES	NO	3556	14.33	2.02	35.8	209	6765	37.02	290.06	2.23	15.59	1544
RICE LAKE	YES	NO	3360	12.10	2.10	36.0	233	6452	39.50	294.45	2.26	25.92	1822
ST. MARY'S	YES	NO	1237	26.32	0.52	30.7	198	4611	22.87	78.62	1.31	12.06	1788
TORONTO	YES	NO	5729	11.65	1.30	35.2	257	10482	13.46	424.70	2.21	21.95	1921
TORONTO	YES	NO	2687	14.54	0.62	23.0	172	4797	5.56	165.49	1.60	17.91	1554
CONTROL	YES	NO	682	20.51	0.21	30.1	170	1184	2.00	69.84	1.64	13.07	1514
RICE LAKE	YES	YES	699	7.70	0.48	12.7	112	1228	5.73	50.75	1.05	3.79	976
RICE LAKE	YES	YES	2247	25.80	2.01	45.9	340	4404	18.63	183.22	2.88	14.22	3511
RICE LAKE	YES	YES	1679	12.22	1.25	20.7	209	3164	17.92	141.67	2.85	10.41	1902
ST. MARY'S	YES	YES	572	14.55	0.94	17.2	217	1752	7.98	30.90	2.72	7.72	1788
TORONTO	YES	YES	2386	15.25	0.87	20.3	204	4363	6.54	152.40	2.44	10.95	1859
TORONTO	YES	YES	2747	14.82	0.81	22.5	224	5251	8.15	177.84	2.24	12.92	1469

Table [illegible]. [illegible] organic [illegible] found [illegible] as a function of feeding and gut clearance. All values are ug.g^{-1} unless otherwise noted.

STATION	FOOD	PURGE	% LIPID	HCB	HEPTA-CHLOR	HEPTACHLOR EPOXIDE	ALDRIN	a-BHC	b-BHC	ALPHA CHLORDANE	GAMMA CHLORDANE
ALGOMA	NO	NO	4.270	0.000*	0.000	0.000	0.000	0.000	0.000	0.000	0.007
RICE LAKE	NO	NO	6.550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RICE LAKE	NO	NO	8.150	0.000	0.012	0.000	0.000	0.000	0.000	0.017	0.000
ST. MARY'S	NO	NO	6.890	0.000	0.000	0.026	0.000	0.011	0.000	0.000	0.010
ST. MARY'S	NO	NO	2.470	0.000	0.012	0.000	0.000	0.006	0.000	.000	0.000
TORONTO	NO	NO	4.140	0.004	0.000	0.000	0.000	0.004	0.000	0.000	0.000
TORONTO	NO	NO	4.300	0.000	0.000	0.000	0.007	0.000	0.000	0.010	0.000
CONTROL	NO	NO	5.810	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.000
ALGOMA	NO	NO	8.870	0.011	0.000	0.000	0.002	0.011	0.000	0.007	0.000
RICE LAKE	NO	YES	5.990	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000
RICE LAKE	NO	YES	4.240	0.007	0.015	0.008	0.000	0.009	0.000	0.016	0.000
ST. MARY'S	NO	YES	5.550	0.008	0.000	0.000	0.005	0.007	0.000	0.004	0.003
ST. MARY'S	NO	YES	4.780	0.017	0.000	0.000	0.007	0.000	0.000	0.000	0.000
TORONTO	NO	YES	4.730	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
TORONTO	NO	YES	5.730	0.004	0.005	0.000	0.001	0.004	0.000	0.004	0.000
RICE LAKE	YES	NO	5.910	0.004	0.000	0.000	0.000	0.005	0.000	0.000	0.000
RICE LAKE	YES	NO	7.740	0.007	0.000	0.008	0.004	0.000	0.000	0.000	0.000
ST. MARY'S	YES	NO	5.340	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000
TORONTO	YES	NO	6.250	0.007	0.000	0.000	0.003	0.000	0.000	0.004	0.000
TORONTO	YES	NO	4.190	0.000	0.011	0.000	0.002	0.009	0.000	0.006	0.000
ST. MARY'S	YES	NO	6.190	0.009	0.000	0.000	0.005	0.005	0.000	0.010	0.000
ALGOMA	YES	NO	6.240	0.000	0.000	0.000	0.000	0.030	0.130	0.000	0.000
RICE LAKE	YES	YES	4.600	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000
RICE LAKE	YES	YES	7.690	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ST. MARY'S	YES	YES	6.860	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000
TORONTO	YES	YES	4.970	0.000	0.022	0.000	0.000	0.000	0.000	0.004	0.000
TORONTO	YES	YES	6.690	0.014	0.007	0.000	0.000	0.012	0.000	0.003	0.000

* Values listed as 0.000 are below detection

pp-DDE	op-DDT	PCB	HCB/ LIPID	HC/ LIPID	HCE/ LIPID	ALDRIN/ LIPID	a-BHC LIPID	b-BHC LIPID	A-CHLORDANE/ LIPID	G-CHLORDANE/ LIPID	pp-DDE LIPID
0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.017	0.000	0.00	0.000	0.001	0.000	0.000	0.000	0.000	0.002	0.000	0.002
0.000	0.000	0.00	0.000	0.000	0.004	0.000	0.002	0.000	0.000	0.001	0.000
0.000	0.000	0.00	0.000	0.005	0.000	0.000	0.002	0.000	0.000	0.000	0.000
0.004	0.000	0.01	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001
0.036	0.000	0.01	0.000	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.008
0.007	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.001
0.025	0.000	0.00	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.003
0.013	0.000	0.00	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002
0.015	0.000	0.00	0.002	0.004	0.002	0.000	0.002	0.000	0.004	0.000	0.004
0.000	0.000	0.00	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000
0.000	0.000	0.00	0.004	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.009	0.000	0.00	0.001	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.002
0.000	0.077	0.00	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
0.000	0.000	0.00	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
0.000	0.029	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
0.091	0.000	0.00	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.005
0.016	0.000	0.00	0.000	0.008	0.000	0.000	0.002	0.000	0.001	0.000	0.004
0.045	0.000	0.02	0.001	0.000	0.000	0.001	0.001	0.000	0.002	0.000	0.007
0.011	0.000	0.00	0.000	0.000	0.000	0.000	0.005	0.021	0.000	0.000	0.002
0.020	0.000	0.00	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.004
0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.030	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.004
0.020	0.000	0.00	0.000	0.004	0.000	0.000	0.000	0.000	0.001	0.000	0.004
0.012	0.000	0.01	0.002	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.002

op_DDT LIPID	PCB/ LIPID
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.002
0.000	0.002
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.013	0.000
0.000	0.000
0.005	0.000
0.000	0.000
0.000	0.000
0.000	0.003
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.000
0.000	0.001

TABLE 14 Comparison of intact cores and homogenized sediments, with reference to growth and mortality of Hexagenia limbata and Pimephales promelas. Values in parentheses are standard deviations

	SITE A[1]			SITE B[1]			SITE C[2]			CONTROL[1]		
	Percent Mortality	Percent Biomass Change	Relative[3] Growth Inhibition	Percent Mortality	Percent Biomass Change	Relative Growth Inhibition	Percent Mortality	Percent Biomass Change	Relative Growth Inhibition	Percent Mortality	Percent Biomass Change	Relative Growth Inhibition
HEXAGENIA												
Core	47 (5)	-37 (10)	186	0 (0)	129 (35)	20 (5)	45 (33)	22 (15)	86	0 (0)	162 (36)	n.a.[4]
Homogenized	8 (11)	4 (1)	96	8 (11)	47 (16)	54 (19)	71 (12)	-80 (12)	175	0 (0)	107 (17)	n.a.
PIMPHALES												
Core	32 (8)	-43 (6)	514	20 (14)	-36 (9)	414	25 (9)	-30 (14)	328	0 (0)	-7 (5)	n.a.
Homogenized	30 (36)	-39 (19)	680	87 (19)	-868 (187)		13 (5)	-31 (18)	520	7 (5)	-5 (3)	n.a.

1 fine-grained sediment
2 sandy sediment
3 relative to controls
4 not applicable

Figure 1. Biomass changes in Hexagenia limbata nymphs for 10 and 21 day exposure durations

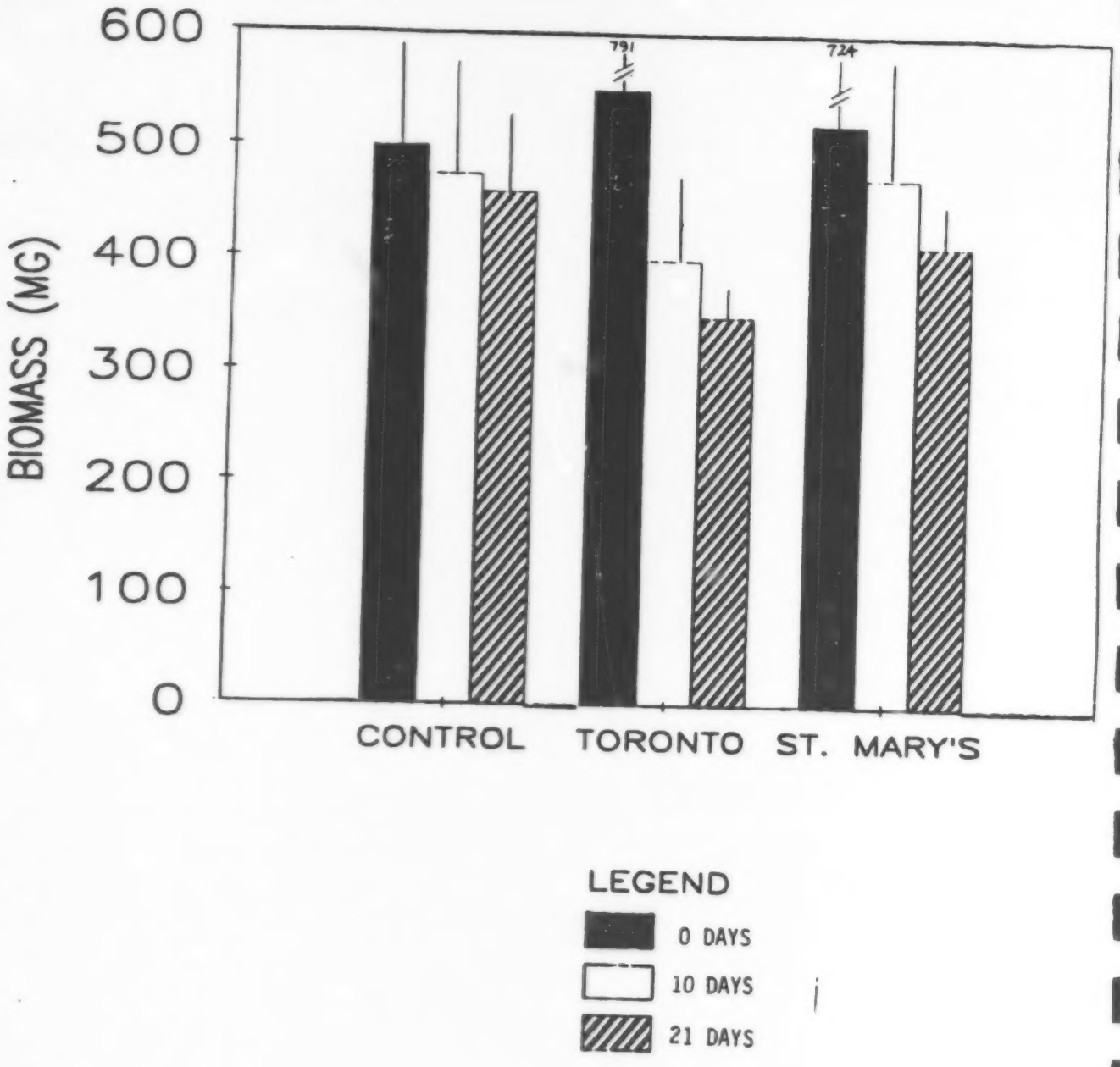

Figure 2. Biomass changes in Pimephales promelas for 10 and 21 day exposure durations

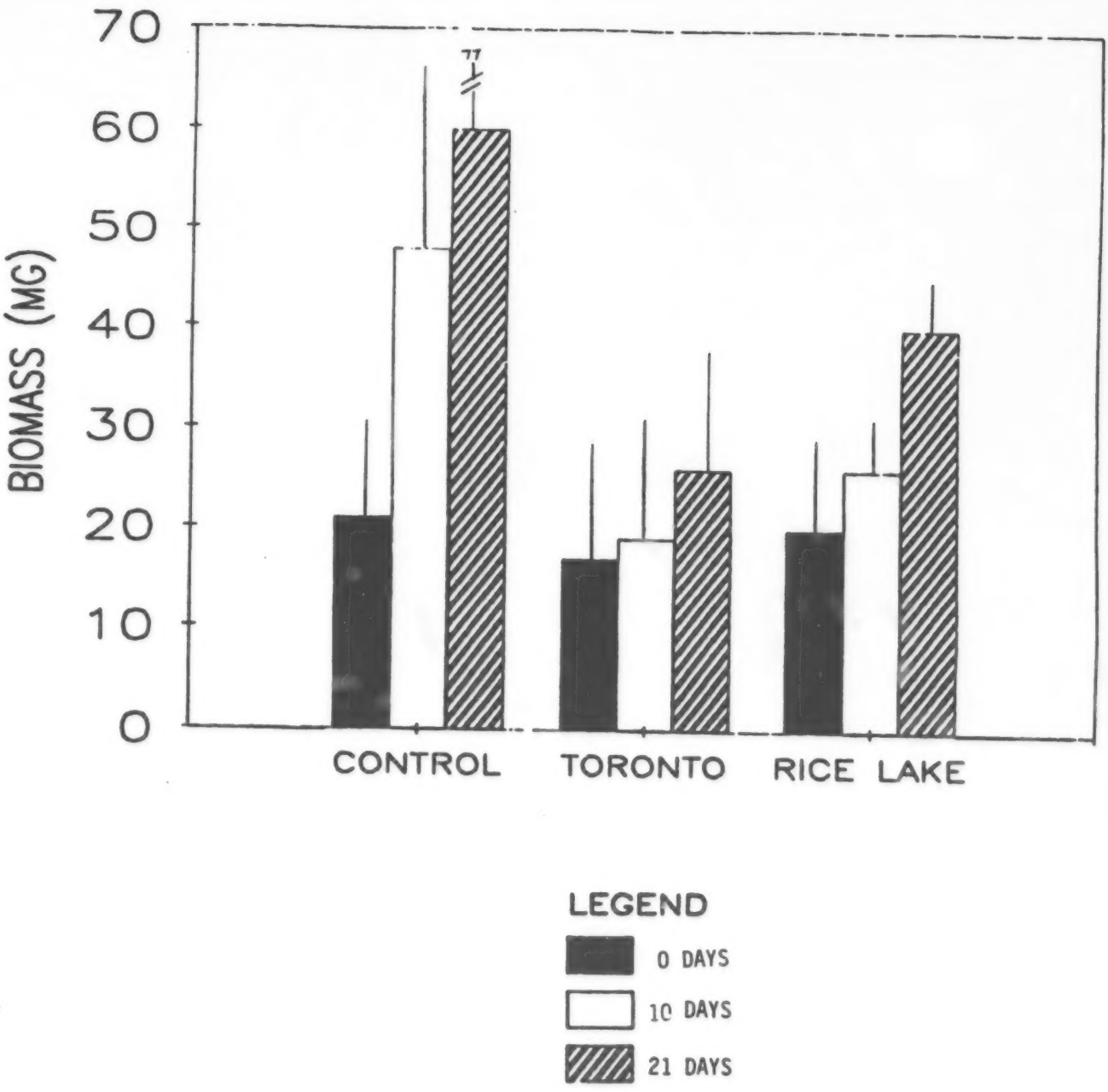

Figure 3

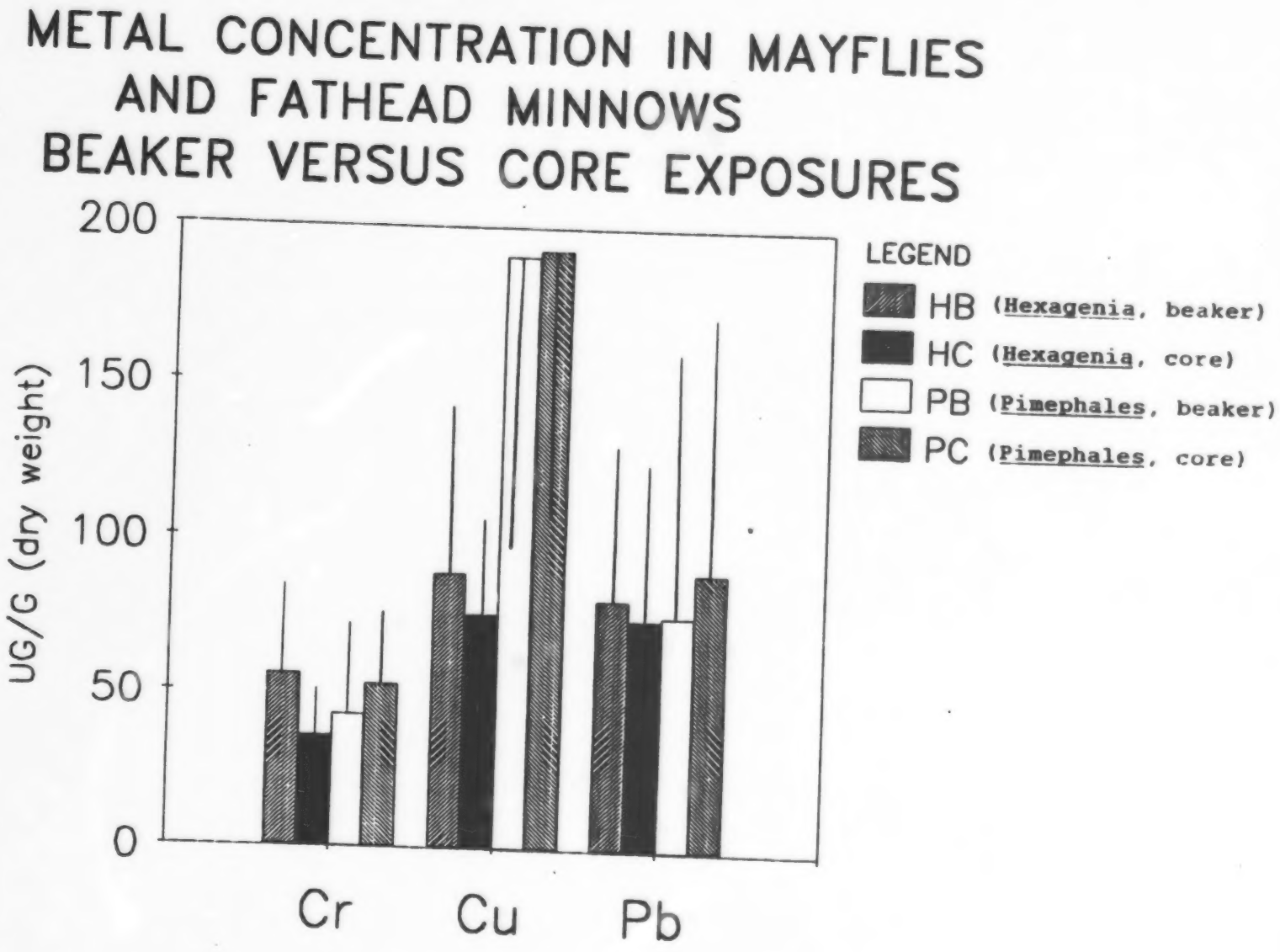
METAL CONCENTRATION IN MAYFLIES
AND FATHEAD MINNOWS
BEAKER VERSUS CORE EXPOSURES
200
150
100
50
0
UG/G (dry weight)
Cr
Cu
Pb
LEGEND
HB (Hexagenia, beaker)
HC (Hexagenia, core)
PB (Pimephales, beaker)
PC (Pimephales, core)

Figure 4

METAL CONCENTRATION IN MAYFLIES AND FATHEAD MINNOWS BEAKER VERSUS CORE EXPOSURES

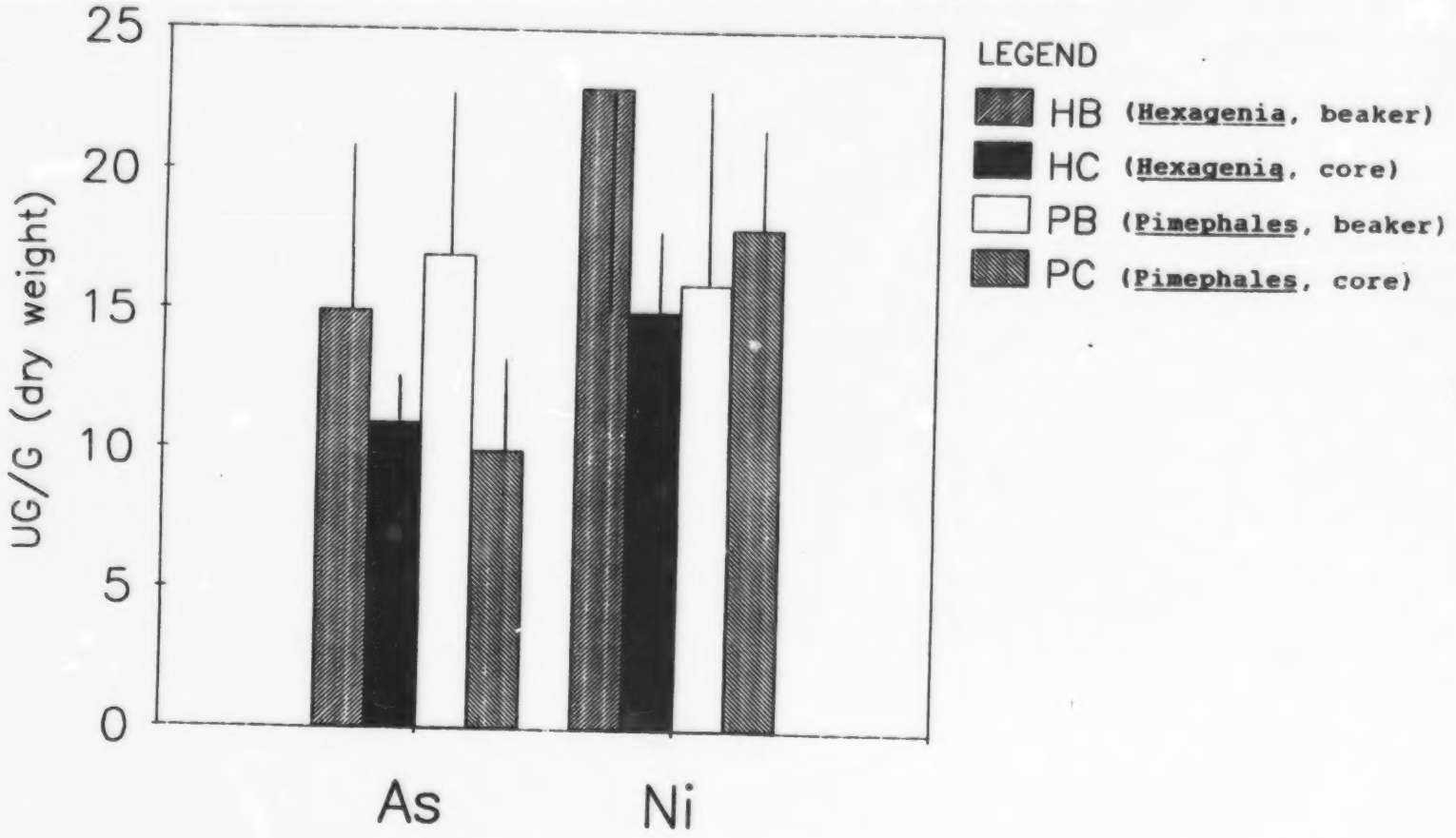

Figure 5

METAL CONCENTRATION IN MAYFLIES AND FATHEAD MINNOWS BEAKER VERSUS CORE EXPOSURES

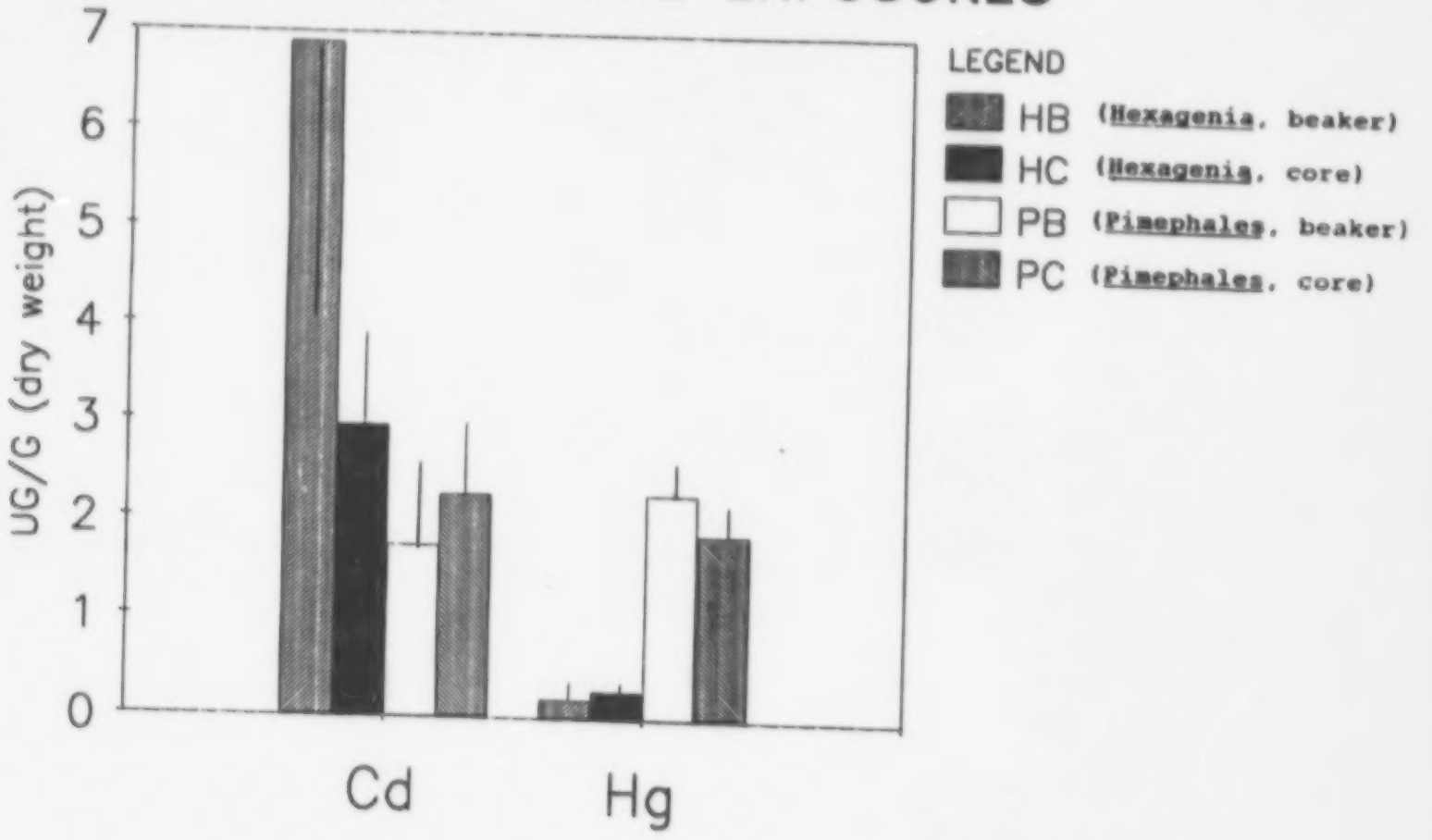

Figure 6

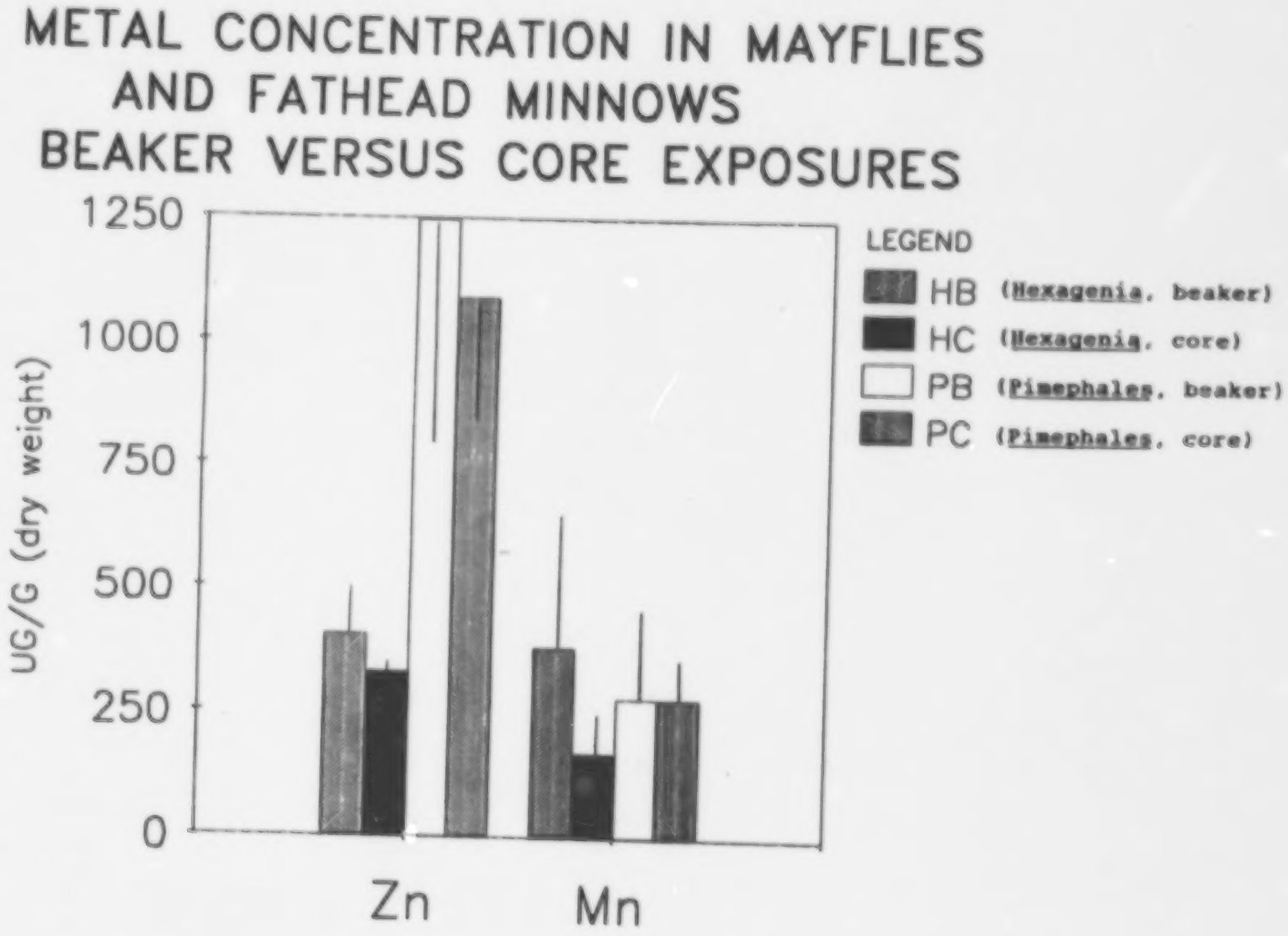
METAL CONCENTRATION IN MAYFLIES
AND FATHEAD MINNOWS
BEAKER VERSUS CORE EXPOSURES
1250
1000
750
500
250
0
UG/G (dry weight)
Zn
Mn
LEGEND
HB (Hexagenia, beaker)
HC (Hexagenia, core)
PB (Pimephales, beaker)
PC (Pimephales, core)

Figure 7

METAL CONCENTRATION IN MAYFLIES AND FATHEAD MINNOWS BEAKER VERSUS CORE EXPOSURES